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THE IMPLICATIONS OF COAL DEVELOPMENT ON THE ATMOSPHERIC ENVIRONMENT AND PLANT ECOSYSTEMS OF SELECTED SITES IN WESTERN NORTH DAKOTA

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THE IMPACT ON AIR QUALITY OF COAL CONSUMING FACILITIES

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THE IMPACT ON AIR QUALITY OF COAL CONSUMING FACILITIES

A Thesis
Submitted to the Graduate Faculty
of the
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By

Theodore Edwin Amundson

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for the Degree of
Master of Science

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1. INTRODUCTION

The ability to predict the environmental impact of new industrial facilities has become a major task for planners in recent years. The need to provide environmental impact statements to satisfy Federal and State regulations requires that accurate predictions of environmental impacts be made. In order to make these predictions the planner will require tools that will enable him to do the task quickly, at a modest cost, and accurately. It is the intent of this thesis to describe methodology which will help the planner to make some of the required estimates. The thesis will describe the methodology to predict the emission rates of air pollutants from point sources. The thesis will also show how the emission rates along with pertinent stack and meteorological data can be used to estimate ground level concentrations of these air pollutants.

The area of environmental impact in which this thesis is concerned is Air Quality. The thesis intends to describe the methodology that will enable the user to make a first estimate of air quality impacts for proposed coal fired electrical generating plants and coal gasification plants. The thesis will describe methods of obtaining estimates of emission rates for the proposed facilities. It will also describe some computer programs that are capable of predicting ground level concentrations of air pollutants from point sources.

The thesis will investigate the possible impact of air quality by a hypothetical coal fired generating plant and a hypothetical coal gasification plant to be built in Western North Dakota. The estimates

made for these facilities make use of the methods described in Chapters 2 and 3 to estimate emission rates of the primary air pollutants. The described computer programs were used to make estimates of downwind concentrations of these air pollutants.

The methods for estimating the products and byproducts from coal fired electrical generating plants and coal gasification plants are described in Chapters 2 and 3, respectively. The methods have been generalized and are applicable to any region. The analysis used to make the estimates is not intended to be a rigorous one, but rather is intended to enable the user to make close first estimate predictions.

Chapter 4 describes three computer programs that predict downwind concentrations of air pollutants from single and multiple point sources. This chapter describes the functions and limitations of each program. The applicable assumptions of the mathematical models are also listed. The necessary input and the resulting outputs are described. Explanations of the computer card decks used to run the programs and examples of the output are also provided.

The last chapters are a study of the impact on air quality by two hypothetical facilities. These facilities, a coal fired electrical generating plant and a coal gasification plant, are to be built in Western North Dakota and will consume North Dakota lignite coal. The applicable meteorological conditions are described for Western North Dakota as well as the applicable Federal and State air pollution regulations. Several methods of controlling the concentrations of air pollutants are discussed and their effect on concentration levels is investigated. The effect of different atmosphere conditions is also

investigated.

The thesis assumes that new coal consuming facilities can be generalized in order to make estimates of initial impacts on the environment. The estimation charts for the coal fired electrical generating plant and the coal gasification plant are the result of a generalized analysis. Consequently, the results obtained from the use of these charts is good only for an initial estimate. No attempt has been made to predict the exact environmental impact from a specified design.

2. ESTIMATION OF BYPRODUCTS FROM POWER PLANTS

This chapter has been prepared for the purpose of estimating coal and water consumption and byproducts for the operation of coal fired electric generating plants at the time a coal development program is being considered.

The use of the estimation charts in this chapter does not require that the plant design be selected and specified. Accordingly, these charts should not be used to determine the absolute amounts of natural resources required or should not be used to determine absolute amounts of byproducts produced. Because some minor assumptions have been used in this study, the charts should be used to determine the level of power plant construction so that impacts on the environment are not above the acceptable level.

Operation of power plants requires large quantities of coal and supplies of water for steam condenser cooling.

Significant byproducts of coal combustion may include:

1. SO_2
2. NO_x
3. Bottom Ash
4. Fly Ash
5. Waste heat

This chapter is intended to estimate the amounts of a) natural resources needed and b) significant byproducts produced at different levels of power plant construction.

All results are expressed in terms of tons of resource or byproduct per megawatt and per year.

2.1 Nomenclature and Symbols

A_b Amount of bottom ash (ash collected by gravity at bottom of furnace), tons/year-megawatt.

A_{bt} The total amount of bottom ash, tons/year.

A_f Amount of fly ash (ash leaving furnace as exhaust), tons/year-megawatt.

A_{ft} Total amount of fly ash, tons/year.

C_c Coal consumption, tons/year-megawatt.

C_t Total amount of coal consumed, tons/year.

F_o Operation factor - an estimate, the actual percentage of time the plant will be in operation divided by 100%.

LHV Lower heating value of coal being used, BTU/lb of coal.

NO_x The amount of nitrogen oxides emitted, tons/year-megawatt.

NO_{xt} Total nitrogen oxides emitted, tons/year.

P_a The percent by weight of ash contained in the coal.

P_s The percent by weight of sulfur contained in the coal.

PHR The heat rate of the plant, BTU/KW-hr.

SO_2 The sulfur dioxide emitted, tons/year.

SO_{2t} The total sulfur dioxide emitted, tons/year.

S_p The size of the plant or plants, megawatts.

W_c Amount of water required by steam condenser, tons/year-megawatt.

W_{ct} The total amount of water required, tons/year.

WH The amount of waste heat released to the total environment, BTU/year-megawatt.

WH_t The total amount of waste heat, BTU/year.

WH_c The amount of waste heat released to the cooling water in the condenser, BTU/year-megawatt.

WH_{ct} Total waste heat to the condenser, BTU/year.

ΔT The change in temperature of the cooling water, degrees fahrenheit (^{o}F).

2.2 Description of Estimation Charts

Figure 2-1 is used to estimate the coal consumption (C_c) in tons of coal per year per megawatt of power produced. The figure assumes the plant operates 24 hours per day, 365 1/4 days per year and that the coal being used has a lower heating value between 6000 and 8500 BTU/lb of coal.

The total quantity of coal consumed in tons/year can be calculated by:

$$C_T = C_c \ (S_p) \ (F_o) \tag{1}$$

(the value for F_o accounts for the fact the plant(s) may not operate 100% of 24 hrs/day and 365 1/4 days/year).

Figure 2-2 is used to estimate the amount of sulfur dioxide (SO_2) emitted in tons per year per megawatt, using the value of C_c from Figure 2-1.

The total quantity of SO_2 emitted in tons/year can be determined by:

$$SO_{2T} = (SO_2) \ (S_p) \ (F_o) \tag{2}$$

Figure 2-3 is used to estimate the amount of NO_x emitted to the environment in tons/year-megawatt. Because NO_x formation is not only dependent on the amount of coal consumed but also dependent on the actual combustion process, the assumption has been made that $NO_x = .004 \ (C_c)$.

The total amount of NO_x emitted in tons/year can be calculated by:

$$NO_{xt} = NO_x \ (S_p) \ (F_o) \tag{3}$$

Figure 2-4 is used to estimate the amount of bottom ash (A_B)

in tons per year per megawatt of power produced. The figure assumes that 20% of the ash produced is collected by gravity at the bottom of the furnace.

The total amount of bottom ash in tons per year can be calculated by:

$$A_{BT} = A_B\ (S_p)\ (F_o) \tag{4}$$

Figure 2-5 is used to estimate the amount of fly ash (A_f) or particulates leaving the furnace in tons per year per megawatt. This figure assumes that the 80% of the ash not collected by gravity in the furnace will be part of the combustion gasses leaving the furnace.

The total amount of fly ash in tons/year can be calculated by:

$$A_{ft} = A_f\ (S_p)\ (F_o) \tag{5}$$

Figure 2-6 is used to determine the amount of heat energy (WH) rejected to the total environment in terms of BTU per year per megawatt.

The total amount of waste heat in BTU per year can be calculated by:

$$WH_t = WH\ (S_p)\ (F_o) \tag{6}$$

Figure 2-7 is used to estimate the amount of heat rejected to the condenser water (river, lake, or pond) (WH_c) in BTU per year per megawatt. The figure assumes that between 10 and 20 percent of the total waste heat leaves the stack and the remaining 80 to 90 percent is dissipated in the condenser.

The total amount of heat rejected to the condenser in BTU/year can be calculated by:

$$WH_{ct} - WH_c\ (S_p)\ (F_o) \tag{7}$$

Figure 2-8 is used to estimate the amount of water that will be required by the condenser in tons per year per megawatt.

The total amount of cooling water required in tons/year can be calculated again by:

$$W_{ct} = W_c \ (S_p) \ (F_o) \qquad (8)$$

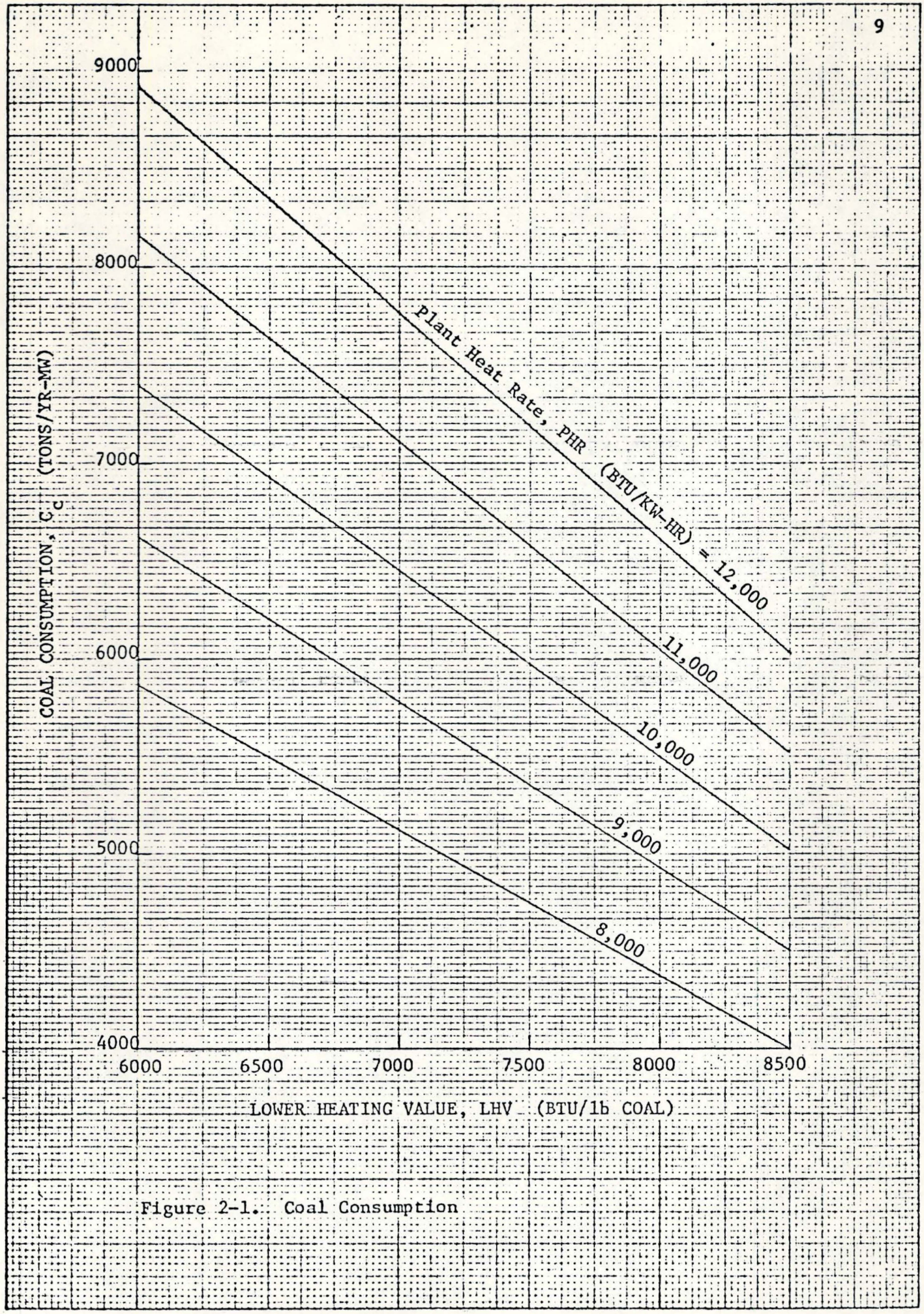

Figure 2-1. Coal Consumption

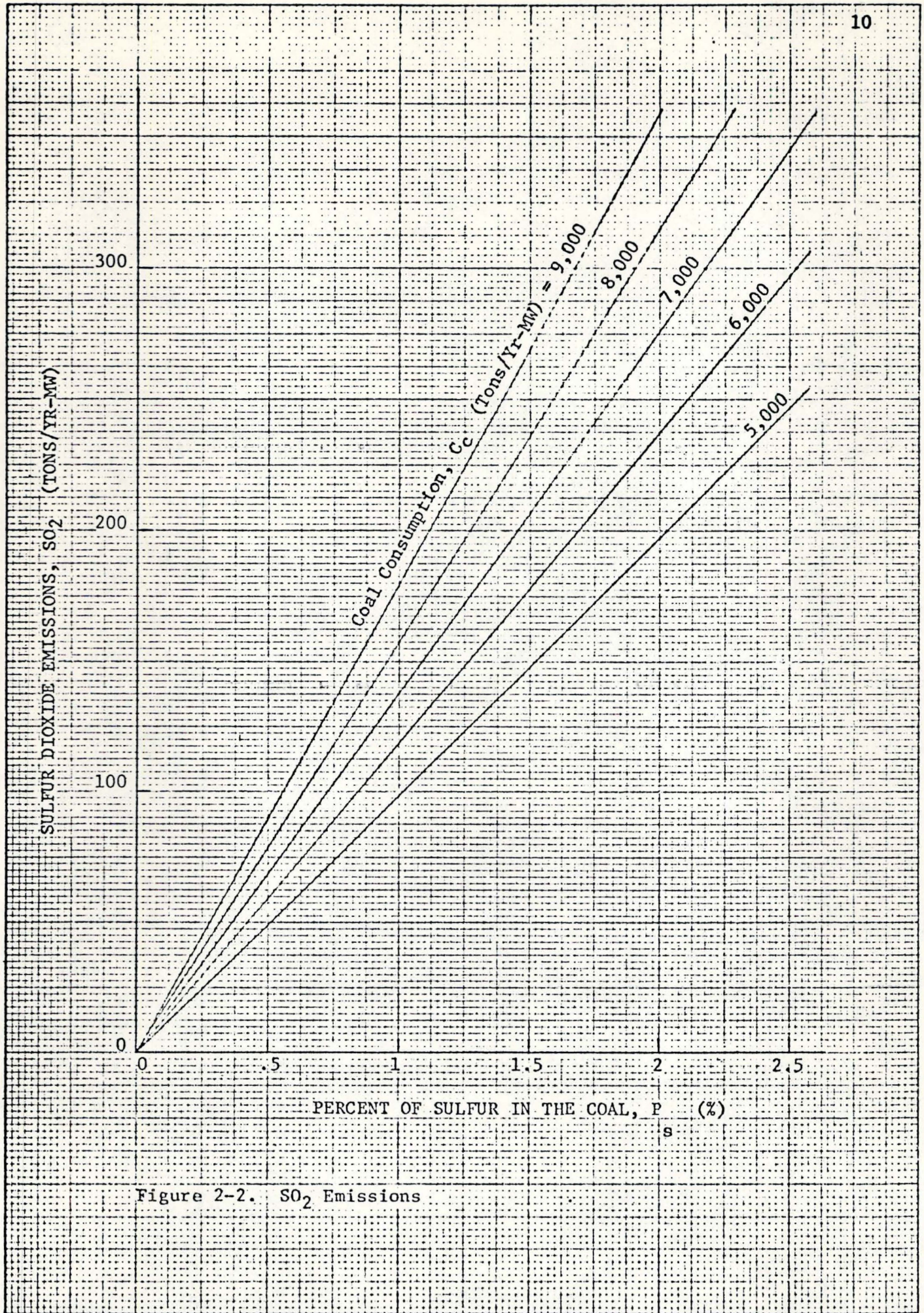

Figure 2-2. SO_2 Emissions

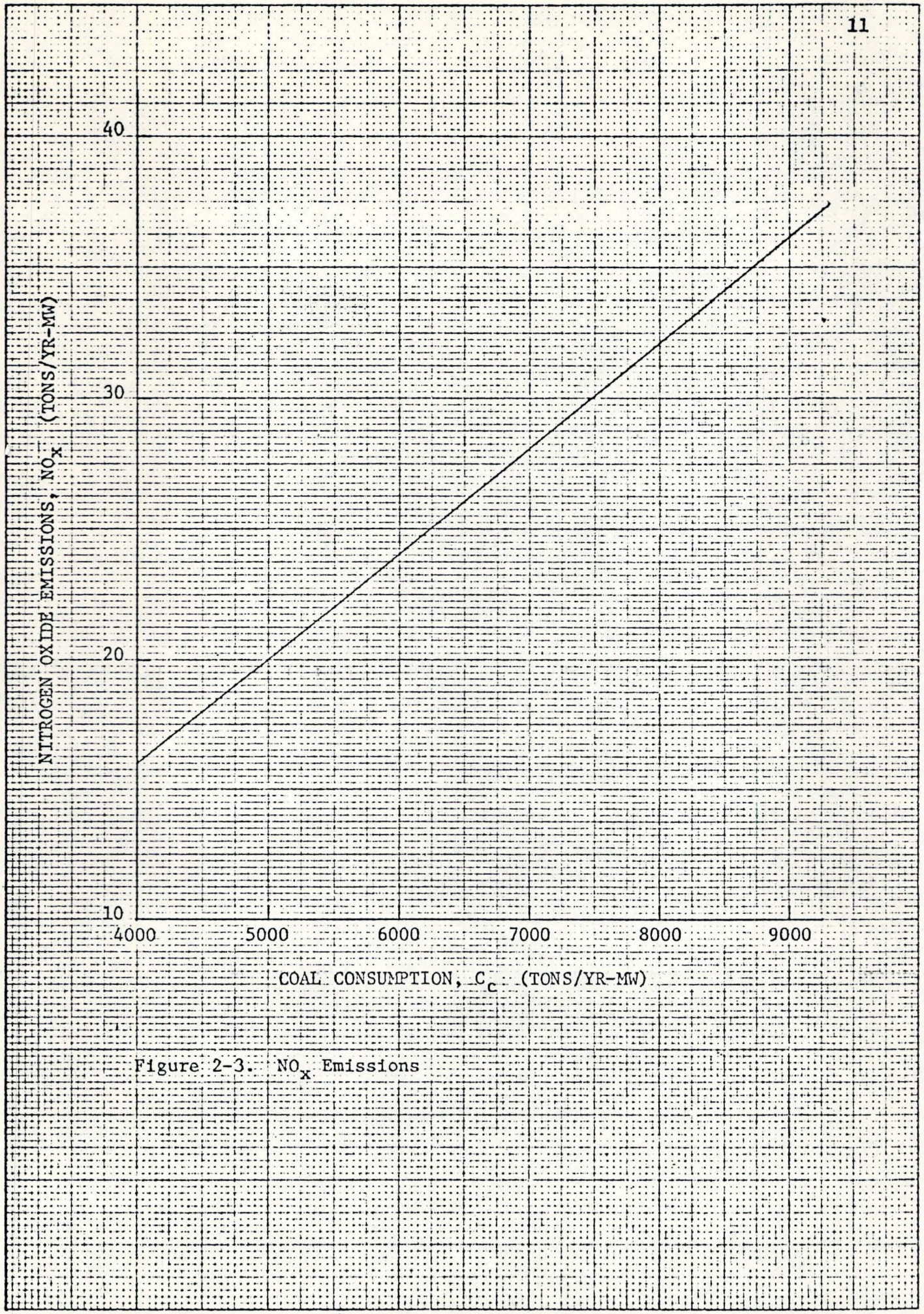

Figure 2-3. NO_x Emissions

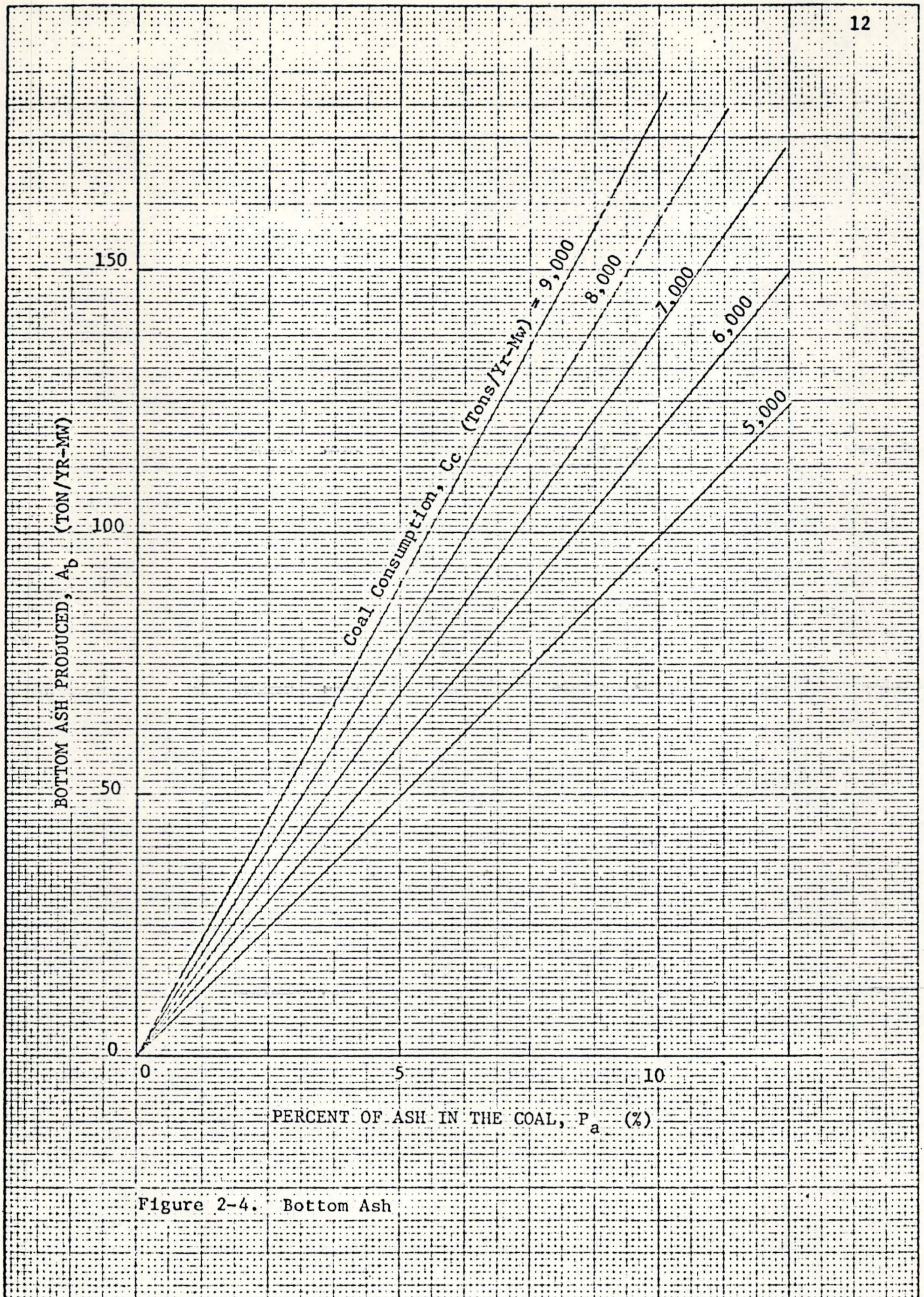

Figure 2-4. Bottom Ash

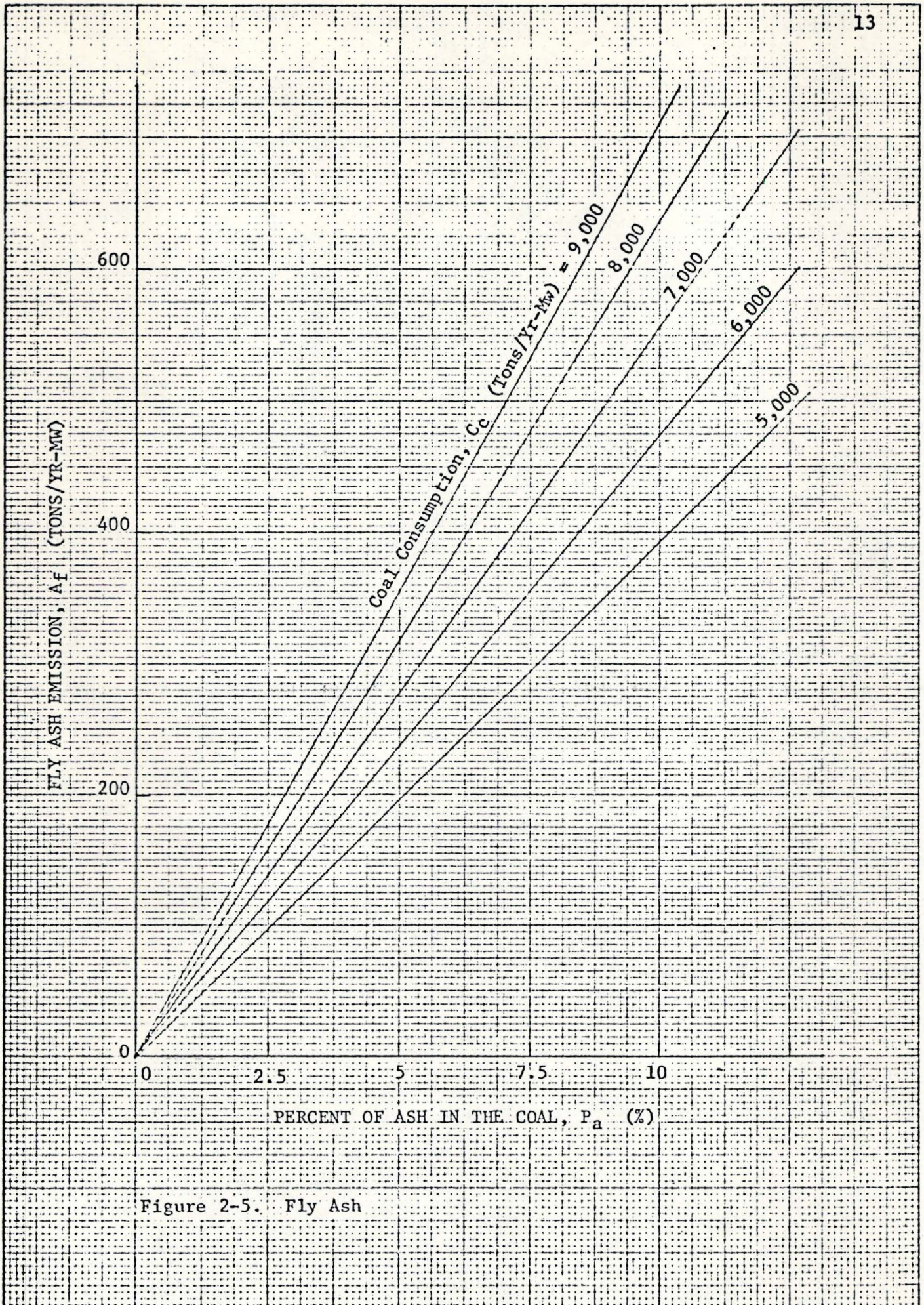

Figure 2-5. Fly Ash

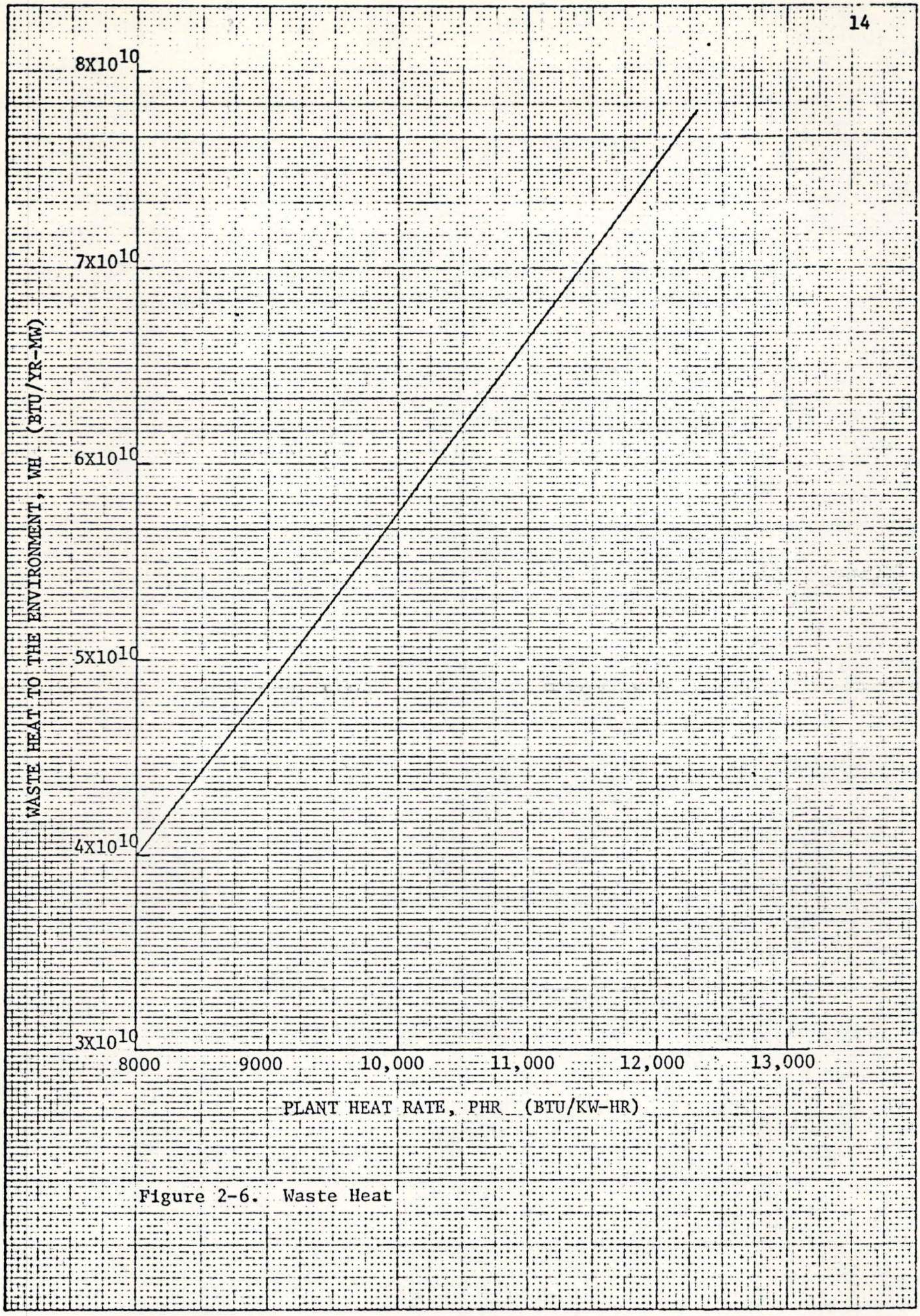

Figure 2-6. Waste Heat

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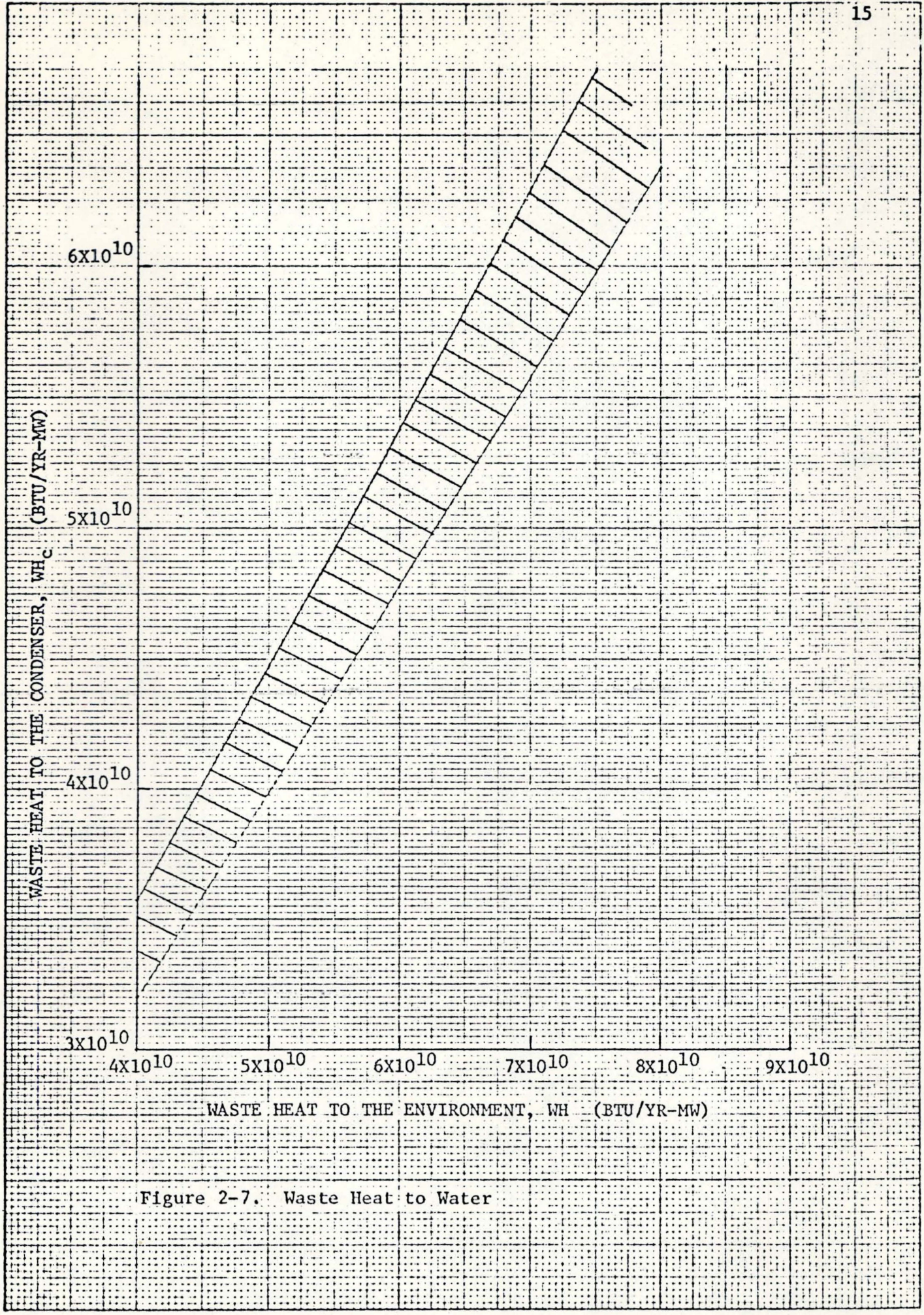

Figure 2-7. Waste Heat to Water

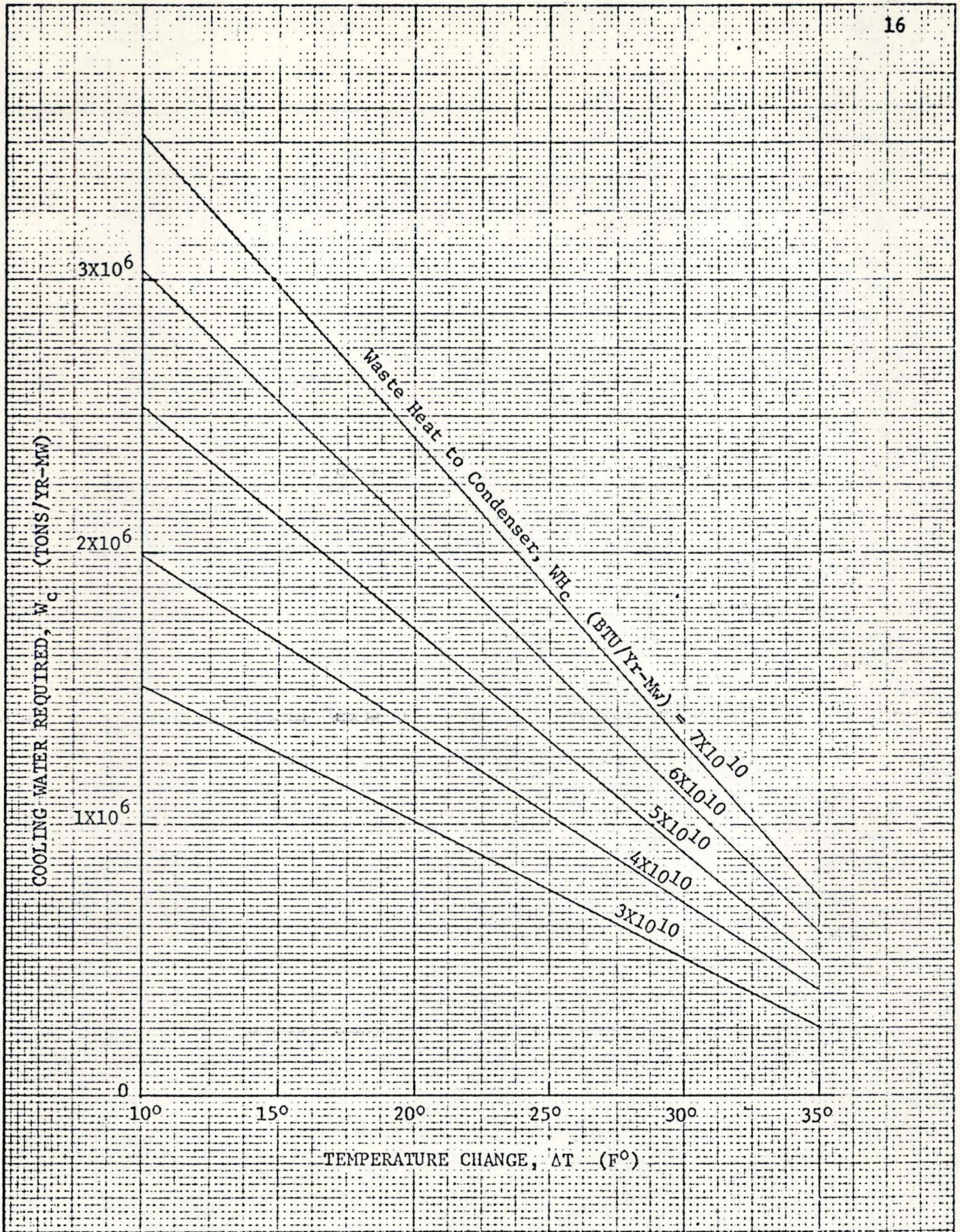

Figure 2-8. Cooling Water

2.3 Sample Calculations

A new 1000 megawatt coal fired power generating plant is to be constructed in North Dakota using N.D. lignite as fuel. It is estimated the plant will be in operation 90% of the time (F_o) and have a plant heat rate (PHR) of 10,000 BTU/kw-hr. The lignite has been analyzed and has the following characteristics:

moisture - 34.2%

volatile matter - 28.1%

fixed carbon - 30.3%

ash - 6.8%

sulfur - 0.60%

LHV (BTU/lb of coal) - 6614

Estimate the coal and water consumption and the amounts of byproducts of the plant.

Coal Consumption

With a lower heating value (LHV) of 6614 BTU/lb of coal and a plant heat rate (PHR) of 10,000 BTU/kw-hr, one can determine from Figure 2-1 that the coal consumption

$$C_c = 6650 \text{ tons/yr-mw.}$$

With an operation factor (F_o) of .9 and the plant size (S_p) being 1000 mw, the total coal consumed using equation 1 is:

$$C_t = 5{,}985{,}000 \text{ tons/yr}$$

SO_2 Emission

The percentage of sulfur in the coal (P_s) is 0.60% and the coal consumption (C_c) has been found to be 6,650 tons/yr-mw; therefore, from Figure 2-2 the sulfur dioxide emission (SO_2) is:

$$SO_2 = 80 \text{ tons/yr-mw.}$$

By equation 2, the total SO_2 emission is:

$$SO_{2t} = 72{,}000 \text{ tons/yr.}$$

NO_x Emission

Knowing the coal consumption to be 6,650 tons/yr-mw, the nitrogen oxides (NO_x) emitted can be found from Figure 2-3 to be: NO_x=26.4 tons/yr-mw. By equation 3, the total NO_x emission is:

$$NO_{xt} = 23{,}760 \text{ tons/yr.}$$

Bottom Ash

With the percentage of ash (P_a) in the coal being 6.8% and the coal consumption again at 6,650 tons/yr-mw, from Figure 2-9 one can determine that the amount of ash collected at the bottom of the furnace (A_b) is:

$$A_b = 85 \text{ tons/yr-mw.}$$

Again, with F_o equal to .9 and S_p of 1000 mw, the total bottom ash (A_{bt}) can be calculated from equation 4 to be 76,500 tons/yr.

Fly Ash or Particulate

Similarly, with the percentage of ash in the coal (P_a) of 6.8%

and the coal consumption of 6,650 tons/yr-mw, the emission rate of fly ash (A_f) can be determined from Figure 2-5 as A_f = 385 tons/yr-mw.

Using equation 5, the total amount of fly ash or particulate (A_{ft}) can be calculated and is 346,500 tons/yr.

Waste Heat

With PHR equal to 10,000 BTU/kw-hr, one can determine the waste heat to the total environment (WH) from Figure 2-6 is 5.77×10^{10} BTU/yr-mw.

Continuing with F_o equal to .9 and S_p equal to 1000 mw, the total waste heat to the total environment (WH_t) from equation 6 is 5.19×10^{13} BTU/yr.

Waste Heat to Cooling Water

After the waste heat to the total environment has been determined from Figure 2-6, Figure 2-7 may be used to find the waste heat to the condenser (WH_o) to be from 4.6×10^{10} to 5.2×10^{10} BTU/yr-mw.

The total waste heat to the condenser (WH_{ct}) from equation 7 is calculated to be from 4.12×10^{13} to 4.68×10^{13} BTU/yr.

Cooling Water Requirement

Assuming the river, lake, or pond water has a temperature of 65°F during the summer and knowing the maximum can be 90°F by state regulations, the temperature difference (ΔT) is 25°F. Using this value and an average value of $WH_c = 5 \times 10^{10}$ BTU/yr-mw, the cooling water required by the condenser (W_c) from Figure 2-9 is 1.23×10^6 tons/yr-mw.

Again with F_o = .9 and S_p + 1000 mw, the total cooling water consumption (W_{ct}) from equation 8 is 1.11×10^9 tons/yr.

3. ESTIMATION OF PRODUCTS AND BYPRODUCTS FROM GASIFICATION PLANTS

Events of the past several years have shown that man can no longer rely on easily recoverable petroleum to fuel his factories, homes, and transportation systems. In order to continue the operation of present facilities he has had to turn to new methods of recovering petroleum. One of the petroleum products forecast to be in critically short supply in the future is natural gas. To help alleviate the forecasted shortage, a new method of producing substitute natural gas by gasifying lignite coal has been developed.

This process is of particular interest to North Dakotans since vast deposits of lignite coal lie under the western part of the state. Before these coal deposits are developed, it is important to know the potential effect of coal development on the environment. The intent of this chapter is to introduce a tool that can aid in the prediction of effects of coal development. This tool is a mathematical model of the lurgi coal gasification process, which can be adapted to a computer for fast and easy first estimation analysis.

The mathematical model of the lurgi coal gasification process is designed to predict the consumption of natural resources by the lurgi process. It is also designed to predict the amount of substitute natural gas produced and the production of various byproducts associated with the process.

The natural resources required by the process are: coal, water, and oxygen. The byproducts produced that will be covered by this report are: ash, petroleum byproducts, sulfur, and waste heat. Several other

byproducts, such as trace elements, may be produced by the process, but their estimation is beyond the scope of this thesis.

The model is based on a preliminary engineering assessment of a proposed 250 MMSCFD (million cubic feet of standard dry gas per day) coal gasification plant to be built in North Dakota. Estimates of actual consumption of natural resources and production of byproducts have been generalized from the engineering assessment. It is assumed that this method will provide a model that can be adapted to other regions as well. The model is not intended to be a rigorous analysis of the LURGI process, but is intended to provide a close approximation of consumption of natural resources and production of significant byproducts for a first look analysis.

3.1 Description of the Lurgi Coal Gasification Process

This chapter is based on a typical Lurgi process for converting lignite coal to substitute natural gas. A simplified description of the Lurgi process is given in the following paragraphs.

The first step of the process is the introduction of coal, steam, and oxygen to the Lurgi gasification units. These units produce a raw gas consisting of methane, hydrogen, carbon monoxide, excess steam, and various byproducts and impurities. Ash contained in the coal is removed from the gasifier units as a byproduct of the process. The crude gas leaving the gasifier is cooled and scrubbed with water which removes tars, heavy oils, and phenolics.

The crude gas is transferred to a shift conversion unit which shifts some of the carbon monoxide to carbon dioxide. After passing

through the shifts conversion unit the gas stream is further cooled for the removal of tars, oil byproducts, and residual phenolics.

The gas is next processed in a "Rectisol" unit to remove gaseous sulfur compounds and some carbon dioxide. Pre-cooling at the unit entry also removes naptha byproducts.

The gas stream then enters the methanation unit where carbon dioxide and carbon monoxide are combined with hydrogen to form methane. The gas stream is then compressed and scrubbed for the removal of carbon dioxide before leaving the plant as substitute natural gas.

Hydrocarbon and aqueous condensates are removed from the main gas stream at several points. All of these generated within the gasification complex are combined and sent to tar oil separators where tar, oil, aqueous liquor, and gaseous streams are separated by gravity. The gaseous vent stream is recompressed and returned to the mainstream, the tar and heavy oil are sent to storage awaiting marketing and the liquor stream, known as gas liquor, is sent to a unit for recovery of phenolics. The gas liquor contains phenols, ammonia, carbon dioxide, hydrogen sulfide, and other material.

The gas liquor stream is filtered at the entrance to the phenol recovery unit. After filtering the lurgi phenosoluan process is used to extract phenols from the water. Isopropyl ether is used in the extraction and transfers the phenolic materials from the water phase to the isopropyl ether phase. The extracted phenolic water is further processed by heating and stripping to remove CO_2, H_2S, and NH_3. The water from the processing step is then routed to biological treatment and subsequently reused within the plant. The phenol rich isopropyl

ether leaving the extraction section is further processed to produce a "lean phenol" isopropyl ether which is recycled back to the extraction section and a saleable crude phenol is obtained as a byproduct. The NH_3 stream is upgraded to anhydrous ammonia for sale as fertilizer.

The acid gas streams generated in the various units of the gasification facility are collected and sent to the sulfur recovery plant. Here catalytic converters and tail gas treators are arranged in a configuration designed to attain a goal of 99% removal of the sulfur existing as H_2S in the acid gas stream. The unit is designed to produce a byproduct saleable sulfur. After leaving the sulfur recovery plant, the residual gas stream is incinerated in the boiler plant and the products of combustion are combined with the boiler plant flue gas for further treatment to remove sulfur dioxide.

The gasification plant complex requires a variety of auxiliary processing units and facilities. These include:

1) A cryogenic air fractionation plant;
2) A steam plant for the production of process steam and the generation of electric power;
3) A raw water treatment plant;
4) Plant effluent water treatment and reuse systems; and
5) The solid material handling systems.

A simplified diagram of the coal gasification complex and lurgi process is shown on Figure 3-1.

3.2 Nomenclature and Symbols

A_c Percent by weight of the ash contained in the coal.

A_p Amount of byproduct ash produced (solid waste), tons/day.

C_d Amount of dry coal (carbon and volatile matter) consumed, tons/day MMSCFD.

C_g Amount of coal consumed in the gasifier train, tons/day.

C_p Amount of coal consumed in the power plant, tons/day.

C_s Amount of coal consumed producing steam, tons/day.

C_t Total amount of coal consumed, tons/day.

F_o Operation factor, an estimate of the actual percentage of 24 hours/day, 365 1/4 hours/year the plant will be in operation, and divided by 100%.

LHV Lower heating value of coal.

M_c Percent by weight of moisture contained in the coal.

O_2 Amount of oxygen consumed in the process, tons/day.

P_B Amount of petroleum byproducts produced, tons/day.

R_g Amount of raw gas produced, tons/day.

S_A Amount of sulfur vented to the atmosphere, tons/day.

S_p The size of the plant, MMSCFD.

S_{PA} The percent by weight of sulfur in the coal.

S_R The amount of steam required for the process, tons/day.

S_{RC} The amount of sulfur recoverd, tons/day MMSCFD.

W_C The net amount of water used in the overall plant, tons/day.

W_H The amount of waste heat produced, BTU/day.

η_{TH} Thermal efficiency for the overall plant.

3.3 Description of Estimation Charts and Equations

The first natural resource estimation will be the consumption of coal. Coal is consumed in three ways for the overall process. The major amount of coal consumed is that which is gasified in the gasification train to produce substitute natural gas. Coal is also consumed to fuel an auxiliary power unit which produces electrical power to run the gasification process. Finally, coal is used to produce steam which is used in the gasification process.

Coal Consumed in Gasifier

An analysis of Dunn County, North Dakota, lignite revealed that the composition of the coal is as follows:

Moisture	38.56%
Volatile matter and carbon	54.60%
Ash	6.84%

An analysis of a typical Lurgi process revealed that 61.9 tons/day of dry coal (volatile matter and carbon) are required to produce a million cubic feet of substitute natural gas per day. The amount of raw coal required is then assumed to be a function of dry coal required, moisture content, and ash content. An equation for determining the amount of raw coal required for the process can then be formulated. This equation is found to be:

$$C_g = \frac{C_D\,(S_p)\,(F_o)}{1 - \frac{A_c + M_c}{100}} \qquad (1)$$

Coal Consumed by the Power Plant

The coal consumed by the power plant can be calculated from

estimation charts formulated by Fahn [4]. Assuming a lower heating value of the coal as 6456 BTU/lbm, and assuming a plant heat rate of 9000 BTU/kilowatt-hour the coal consumption would be approximately 17.1 tons/day-megawatt. Assuming a 50 megawatt power plant is required for a plant that produces 250 million cubic feet of gas per day, a 0.2 MW unit would be required for a unit producing one million cubic feet of gas per day. The equation for calculating the coal consumed by the power plant would then be:

$$C_p = 3.42\ (S_p)\ (F_o) \qquad (2)$$

Coal Consumed by Boiler to Produce Steam for the Gasification Process

To determine the amount of coal consumed in producing steam for the gasification process an energy balance is required. Assuming the feedwater to the boiler is saturated water at 50°F and that superheated steam at 415 PSIA and 750°F exits the boiler, and that 7868 lbs/hour-MMSCFD of steam are required, the amount of coal consumed can be found. Assuming a boiler efficiency of 90% and a lower heating value of the coal as 6456 BTU/lbm, the amount of coal consumed can be calculated. The amount of coal consumed is found to be 22.3 tons of coal per day and per MMSCFD. The equation for calculating coal consumed in producing steam is found to be:

$$C_s = .236\ (S_R)\ (S_p)\ (F_o) \qquad (3)$$

The total amount of coal consumed is then the sum of the coal used in the coal gasification process, the power plant, and steam production.

$$C_t = C_g + C_p + C_s \qquad (4)$$

Figure 3-3 is used to predict the amount of oxygen required for the gasification process. The amount of oxygen required is assumed to be directly proportional to the amount of dry coal consumed. By analyzing a typical lurgi process the relationship between oxygen and dry coal can be found. This relationship was found to be:

$$O_2 = 0.126\ C_d\ (S_p)\ (F_o) \tag{5}$$

Figure 3-4 is used to compute the amount of steam for the process. The amount of steam required is directly proportional to the amount of oxygen used in the process. This relationship is found to be 1 mole of steam for 6.5 moles of oxygen. Converting this relationship to units of tons yields:

$$S_R = 3.656\ O_2 \tag{6}$$

Figure 3-5 is used to compute the net water usage for the overall plant. Using a material and energy balance the total water consumption can be found. For a planned 250 MMSCFD plant this was found to be 10,384 gallons per minute. The equation in terms of tons per day is then:

$$W_c = 239\ (S_p)\ (F_o) \tag{7}$$

Figure 3-6 is used to predict the amount of ash that will be produced and returned to the mine. Ash production will be a function of the percent ash content in the coal. An assumption is made that all of the ash in the coal is recoverable. The equation to find the amount of ash produced is then:

$$A_p = \frac{A_c\ (C_t)}{100\%} \tag{8}$$

Figure 3-7 is used to predict the amount of raw gas produced in the gasifiers. Estimation of this product is important since production of petroleum byproducts is assumed to be a function of this parameter. Raw gas production can be formulated by summing the amount of coal, steam, and oxygen to the gasifiers and subtracting the ash produced. The equation for finding the raw gas is given as:

$$R_g = O_2 + S_R + C_g - A_p \tag{9}$$

Figure 3-8 is used to estimate the production of petroleum by-products. The byproducts are in the form of tars, oils, naptha, ammonia, and crude phenols. An examination of a typical lurgi process plant that will produce 250 MMSCFD of substitute natural gas revealed that 1599 tons/day byproducts would be produced. Converting this value to 1 MMSCFD plant and assuming the amount of petroleum byproducts is proportional to the amount of raw gas produced, an equation for determining the petroleum byproduct output can be found. This equation is given as:

$$P_B = .0286\ (R_g) \tag{10}$$

Figure 3-9 is used to estimate the amount of sulfur that will be vented to the atmosphere from the gasification units. Approximately 1% of the sulfur contained in the coal will be vented to the atmosphere. The equation for calculating the amount of sulfur vented to the atmosphere is then:

$$S_A = \frac{.01\ (S_{PA})\ (C_g)}{100\%} \tag{11}$$

Figure 3-10 is used to estimate the amount of sulfur recovered

in collection units of the gasification train. Ninety-nine percent of the sulfur is not vented to the atmosphere. Of this 99% approximately 10-40% will be returned to the mines with the ash. An additional amount will be included in the petroleum byproducts. The majority of the sulfur will be recovered in the sulfur recovery units. The amount of sulfur recovered can be found by the equation:

$$S_{RC} = \frac{.592\ (S_{PA})\ (C_g)}{100\%} \qquad (12)$$

This equation assumes 40% of the sulfur will be returned to the mines with the ash.

Figure 3-11 is used to predict the production of waste heat. The estimation of waste heat production can be accomplished by evaluating a heat balance for the lurgi process. The waste heat produced will be the difference between the energy available in the coal consumed and the energy available in the substitute natural gas the various byproducts. The waste heat is then a function of the thermal efficiency of the plant and the total amount of coal consumed. The equation is given as:

$$w_H = HHUC\ (C_t)\ (1-n_{tH}) \qquad (13)$$

The thermal efficiency is defined as the energy available in the various products of the plant divided by the energy contained in the coal consumed by the gasification plant.

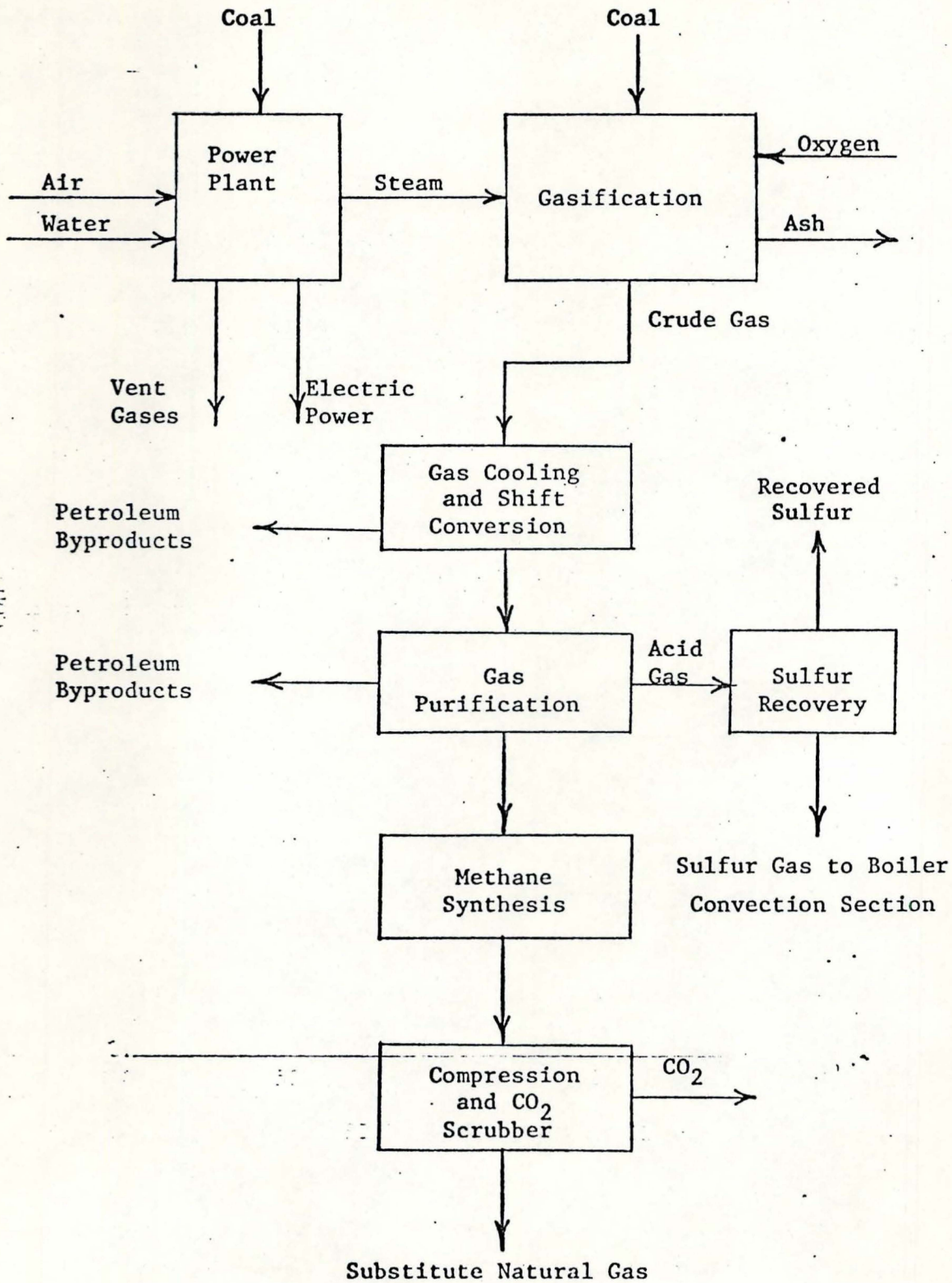

Figure 3-1. Lurgi Process

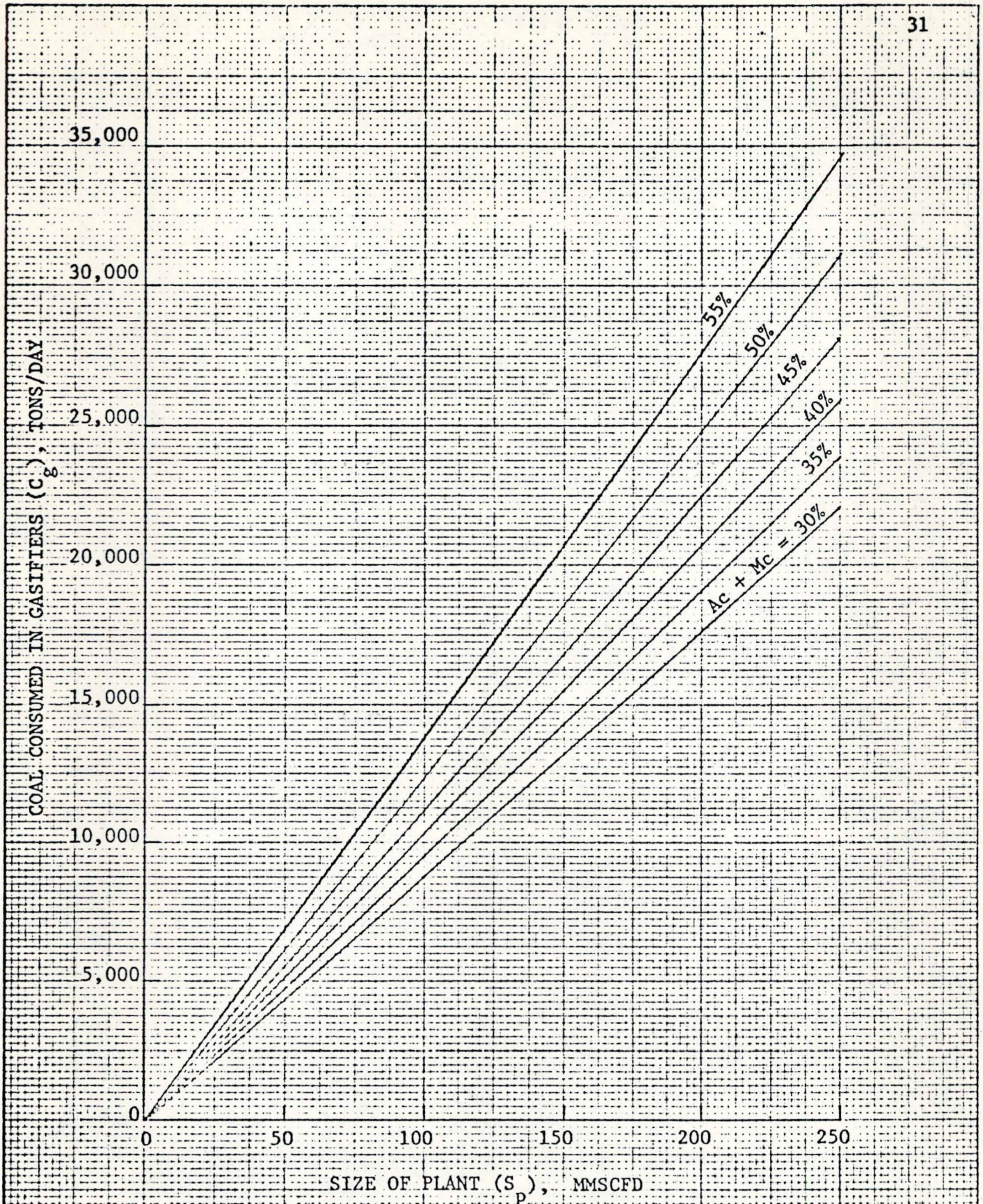

Figure 3-2a. Coal Consumed in Gasifiers C_d = 61.9 Tons/Day

F_o = 1.0

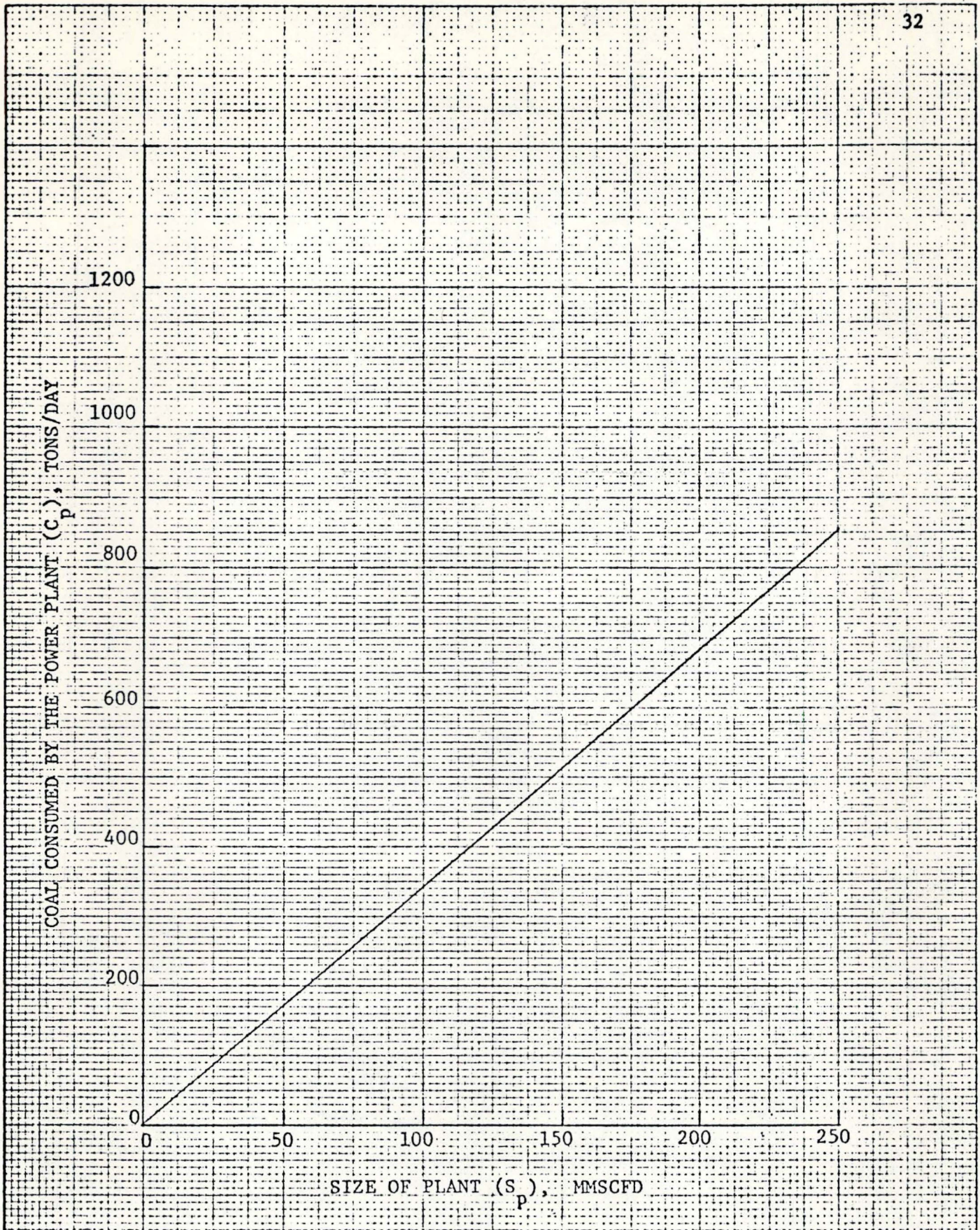

Figure 3-2b. Coal Consumed by the Power Plant $F_o = 1.0$

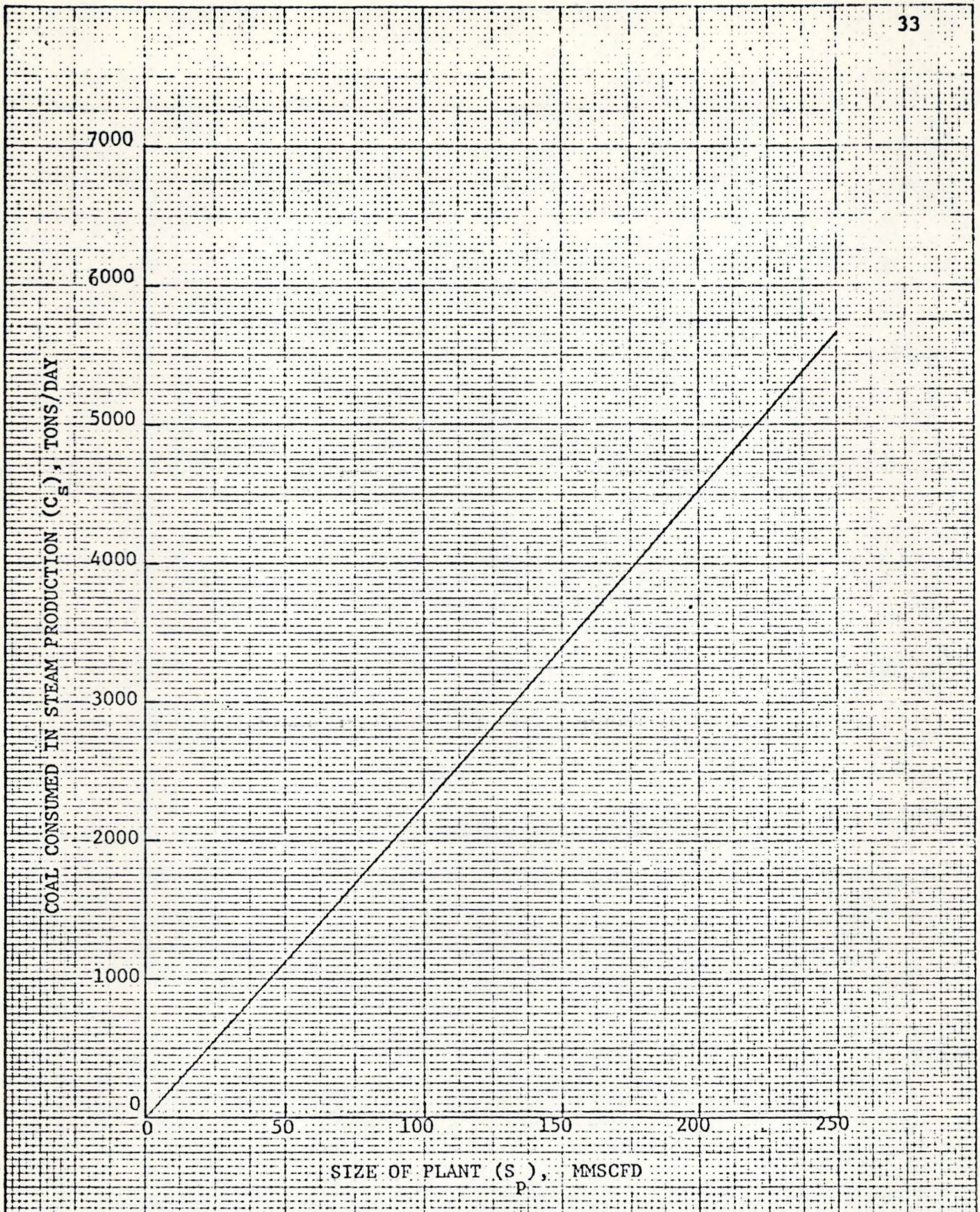

Figure 3-2c. Coal Consumed in Steam Production $F_o = 1.0$

$S_R = 94.4$ Tons/Day

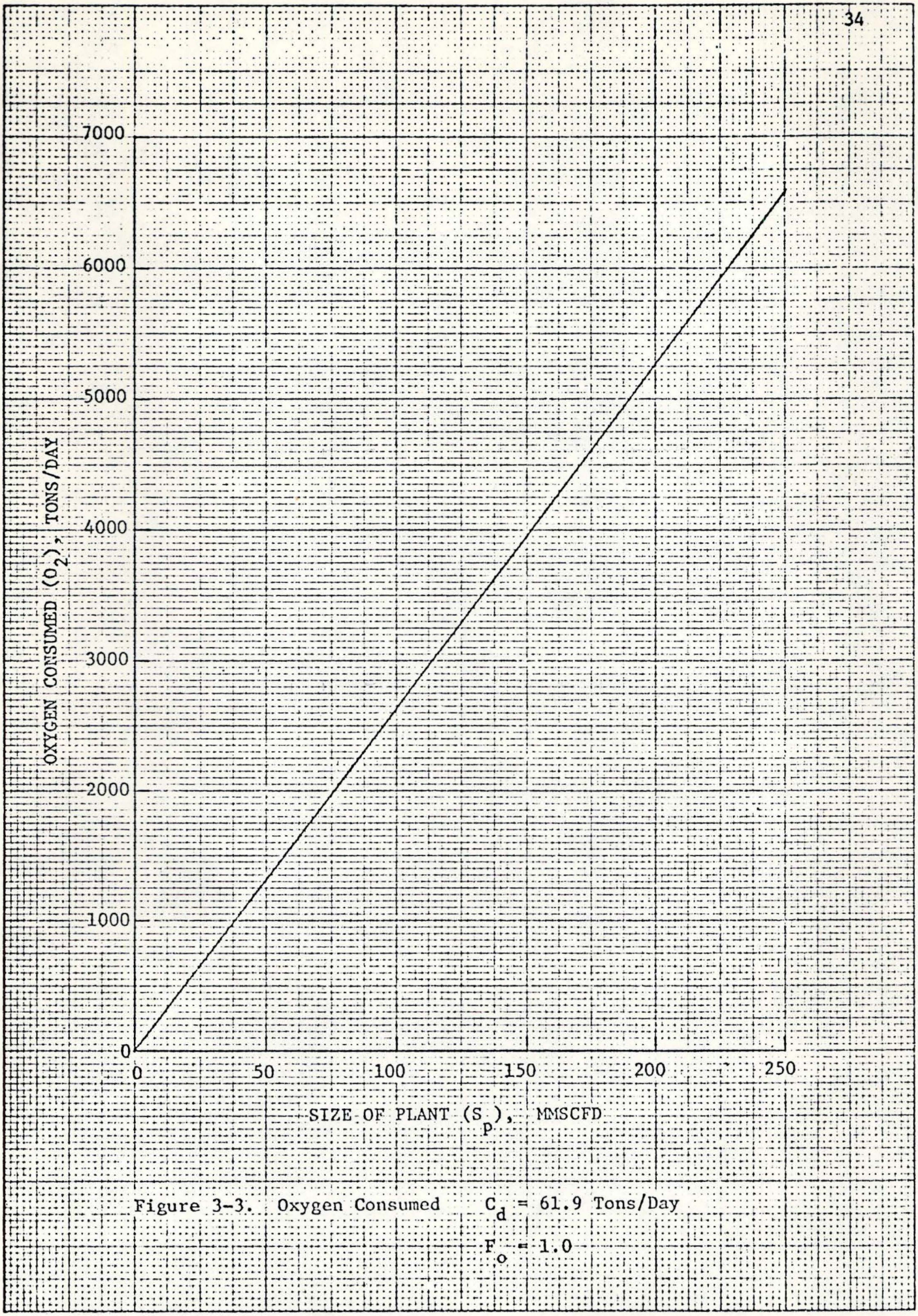

Figure 3-3. Oxygen Consumed C_d = 61.9 Tons/Day

F_o = 1.0

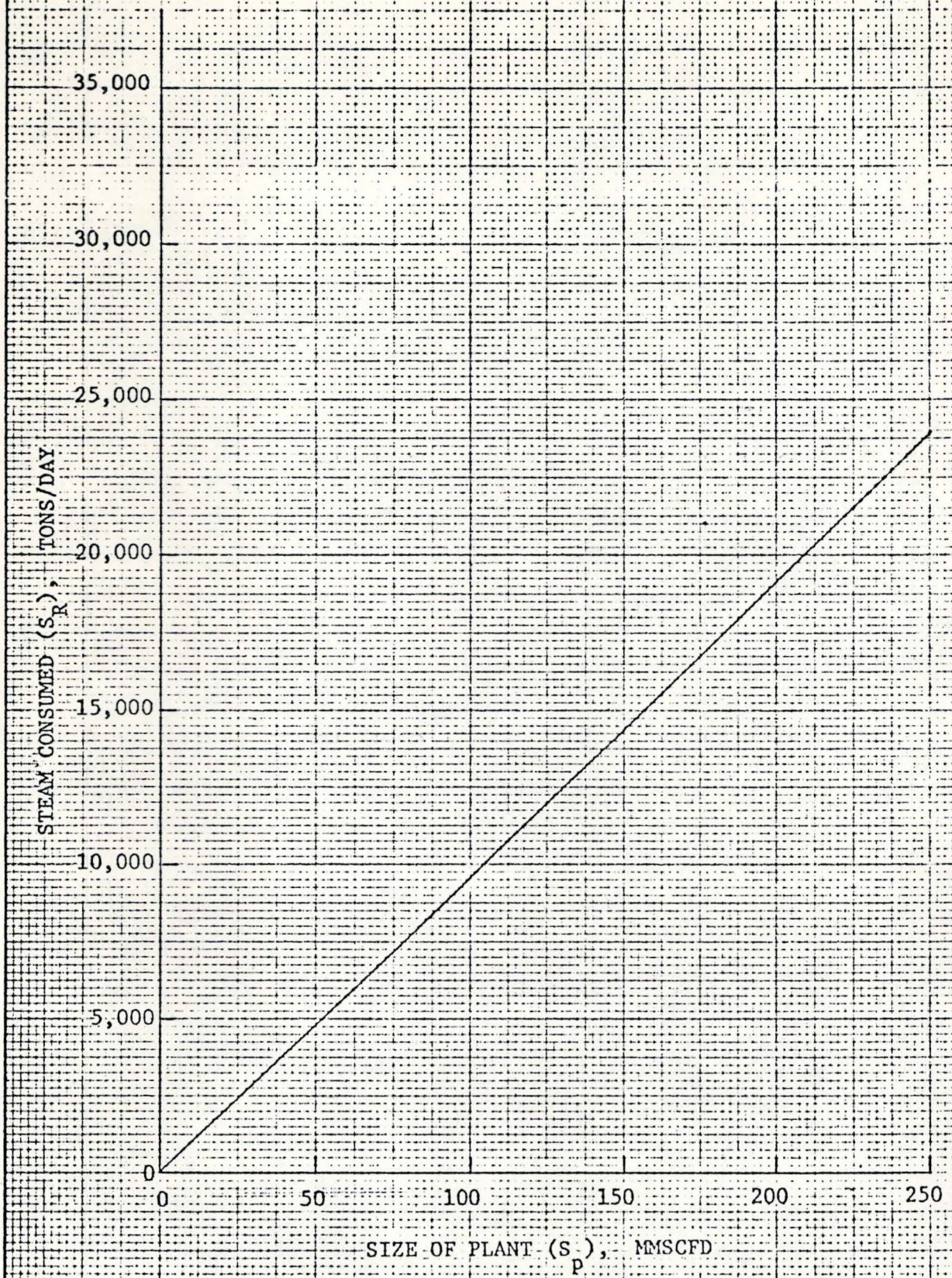

Figure 3-4. Steam Consumed

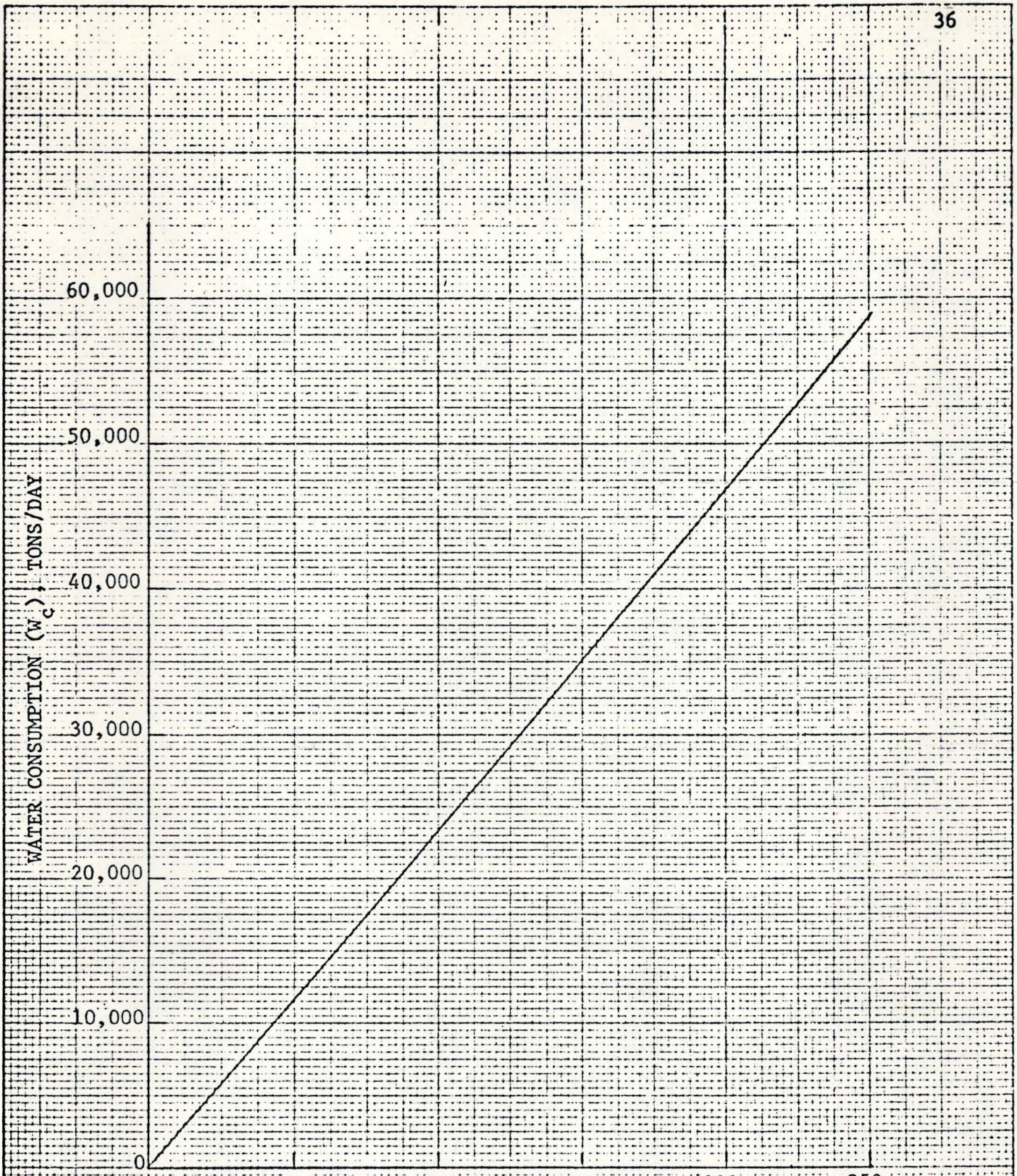

Figure 3-5. Net Water Consumption $F_o = 1.0$

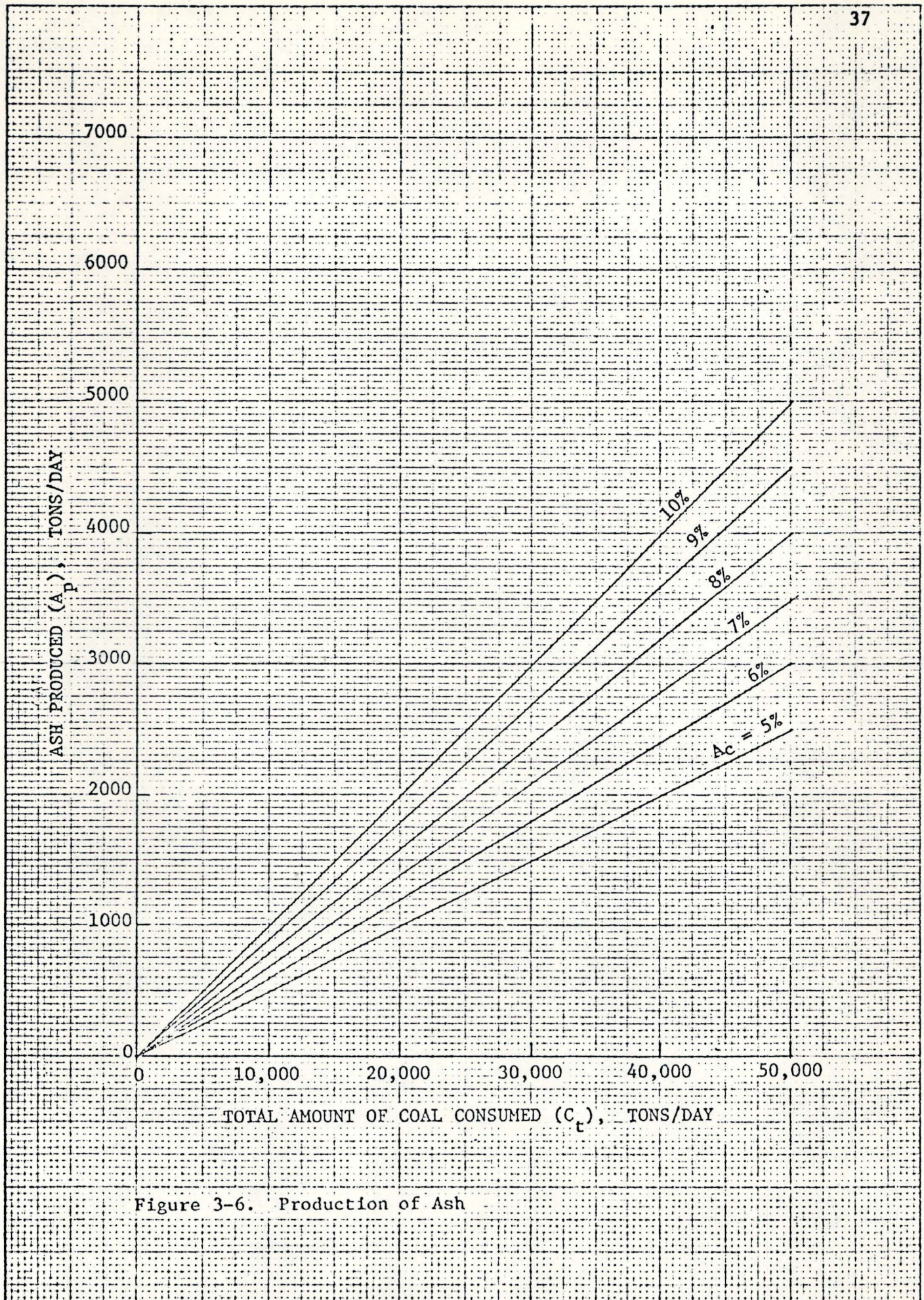

Figure 3-6. Production of Ash

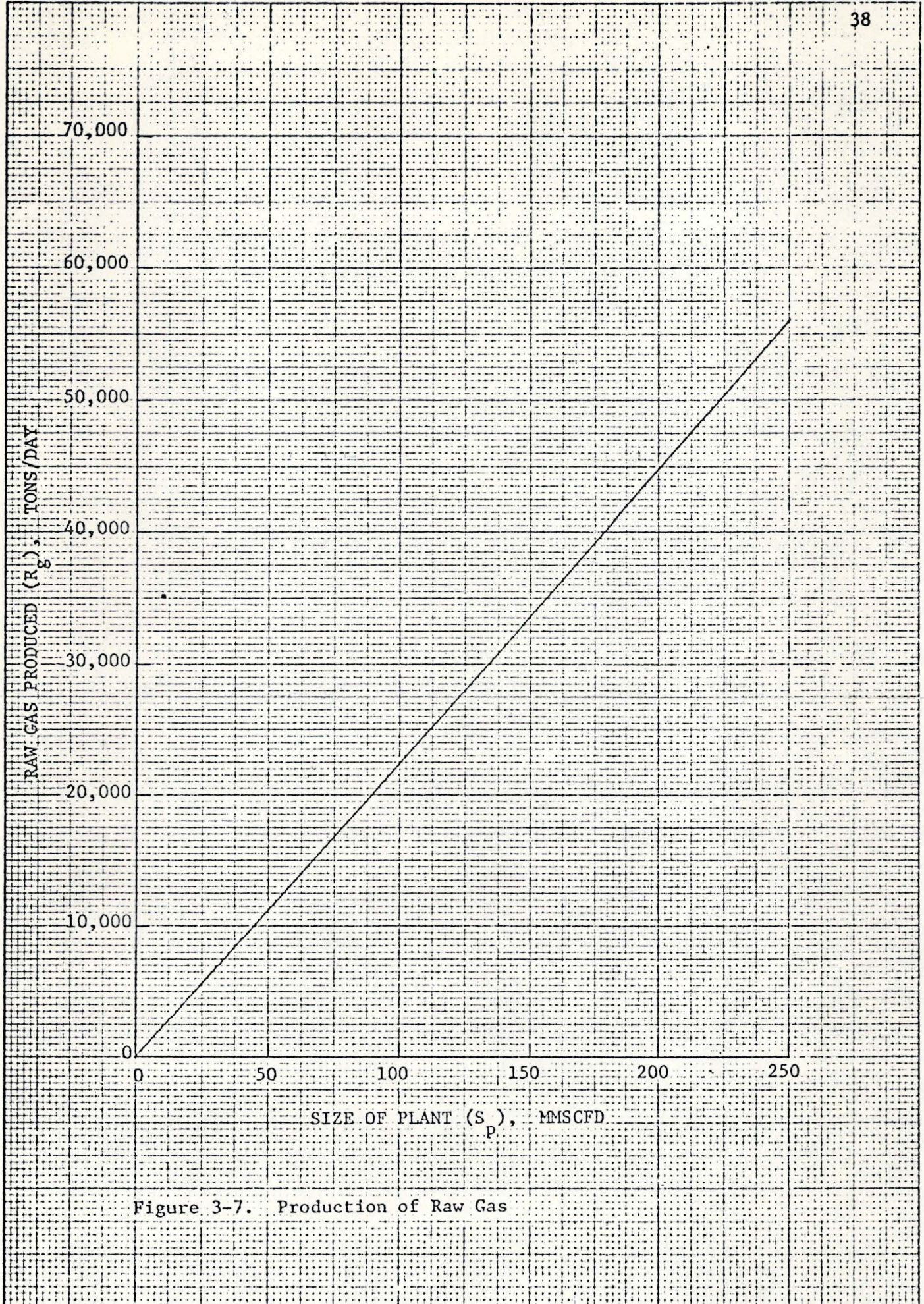

Figure 3-7. Production of Raw Gas

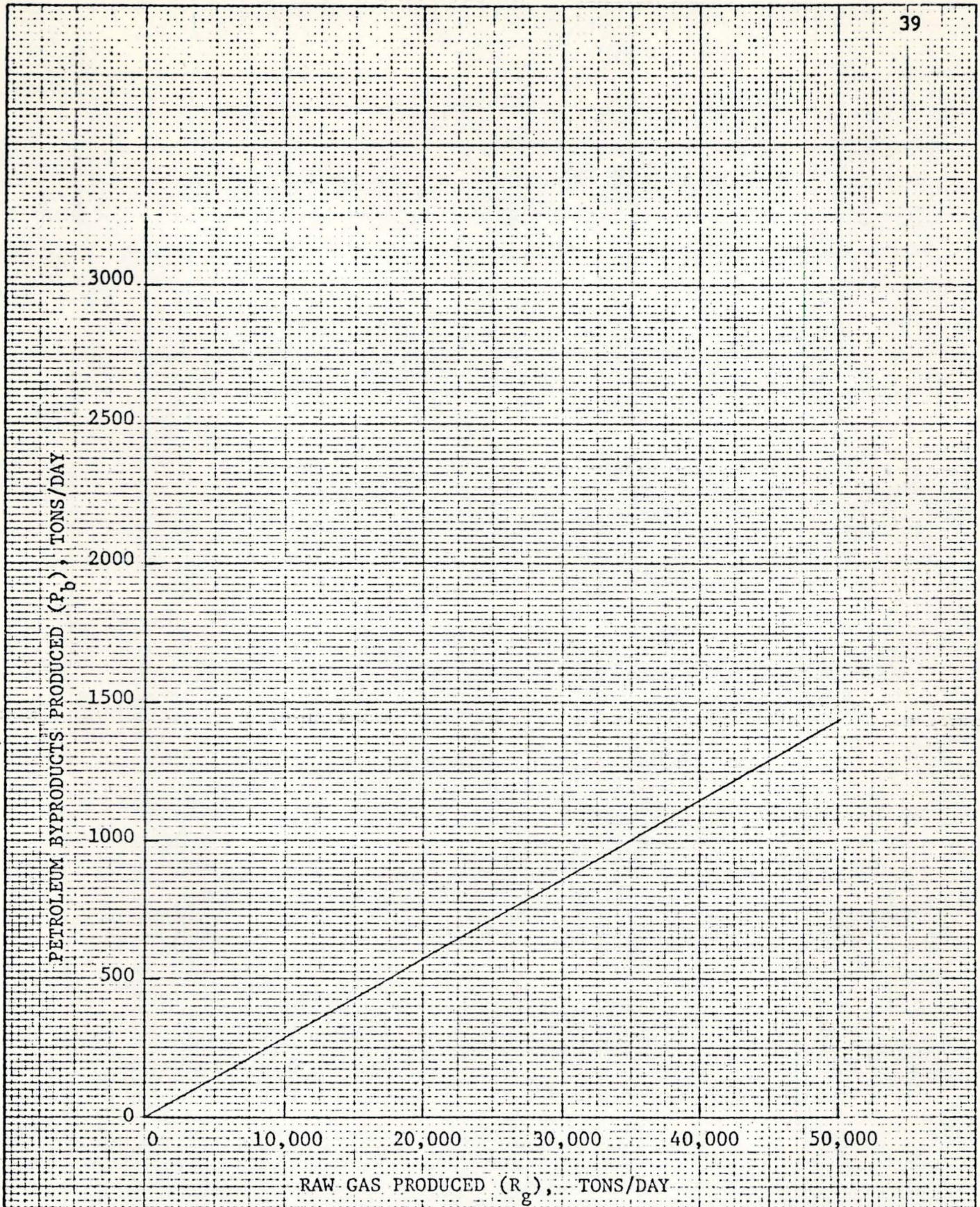

Figure 3-8. Production of Petroleum Byproducts

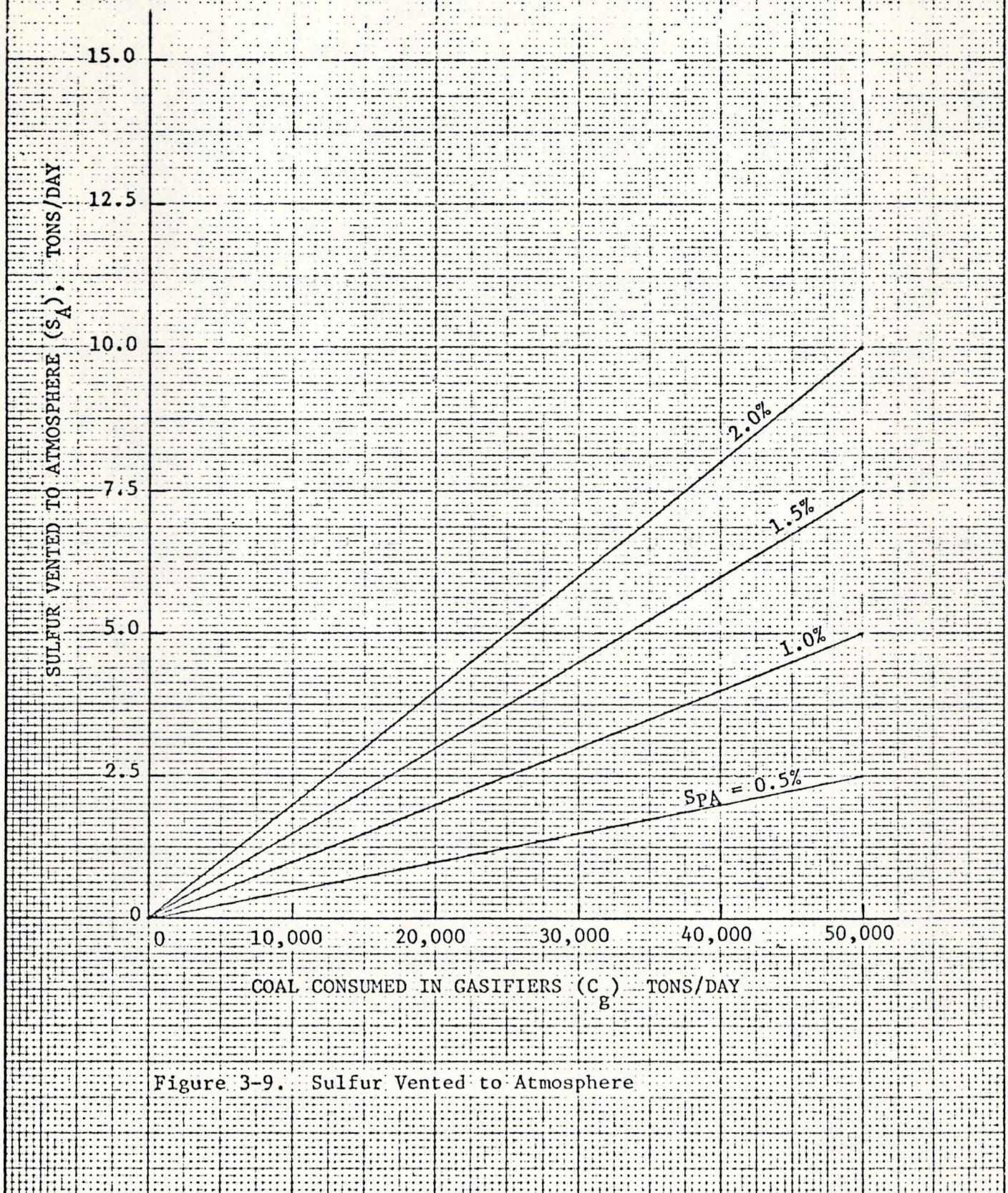

Figure 3-9. Sulfur Vented to Atmosphere

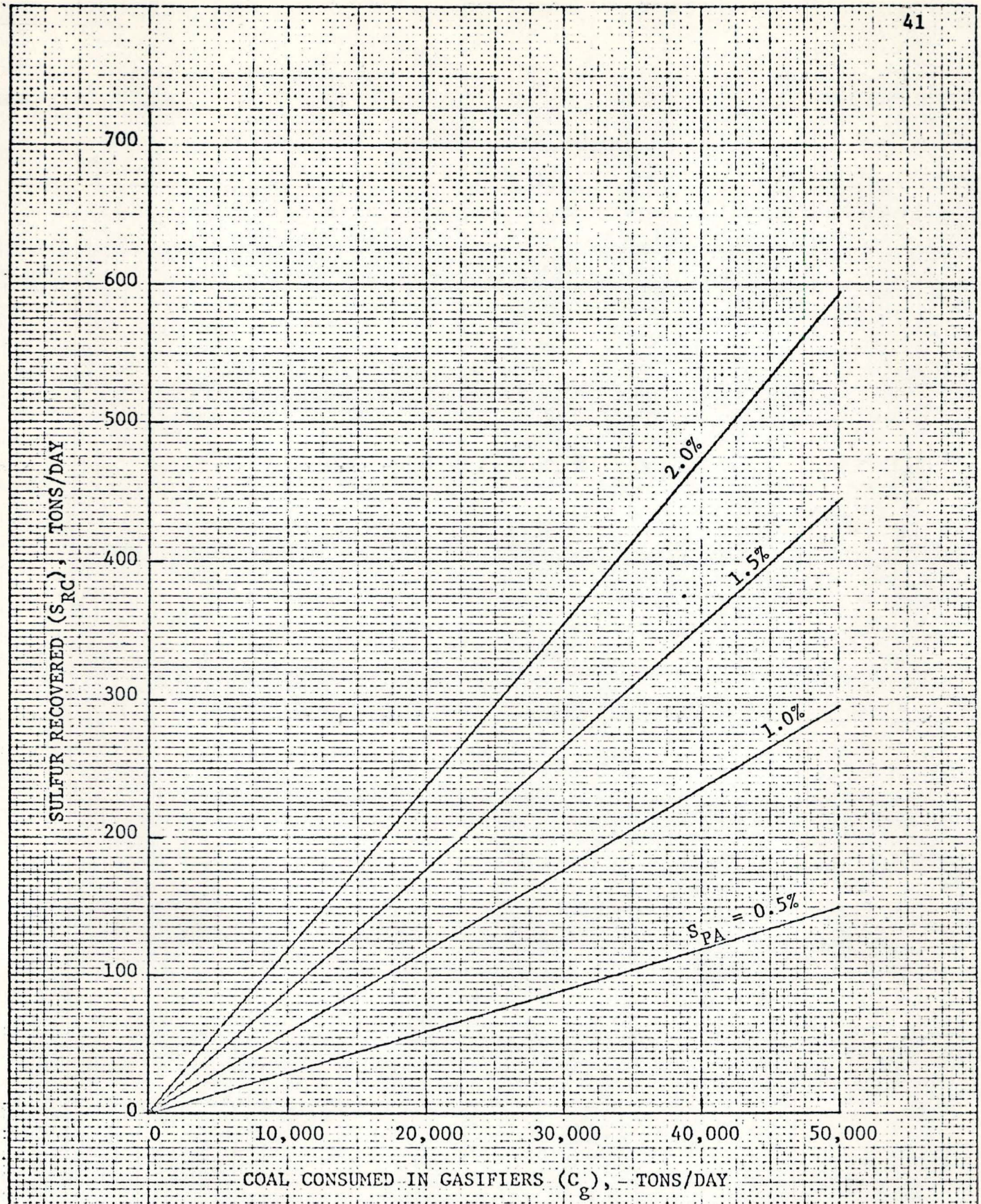

Figure 3-10. Sulfur Recovered

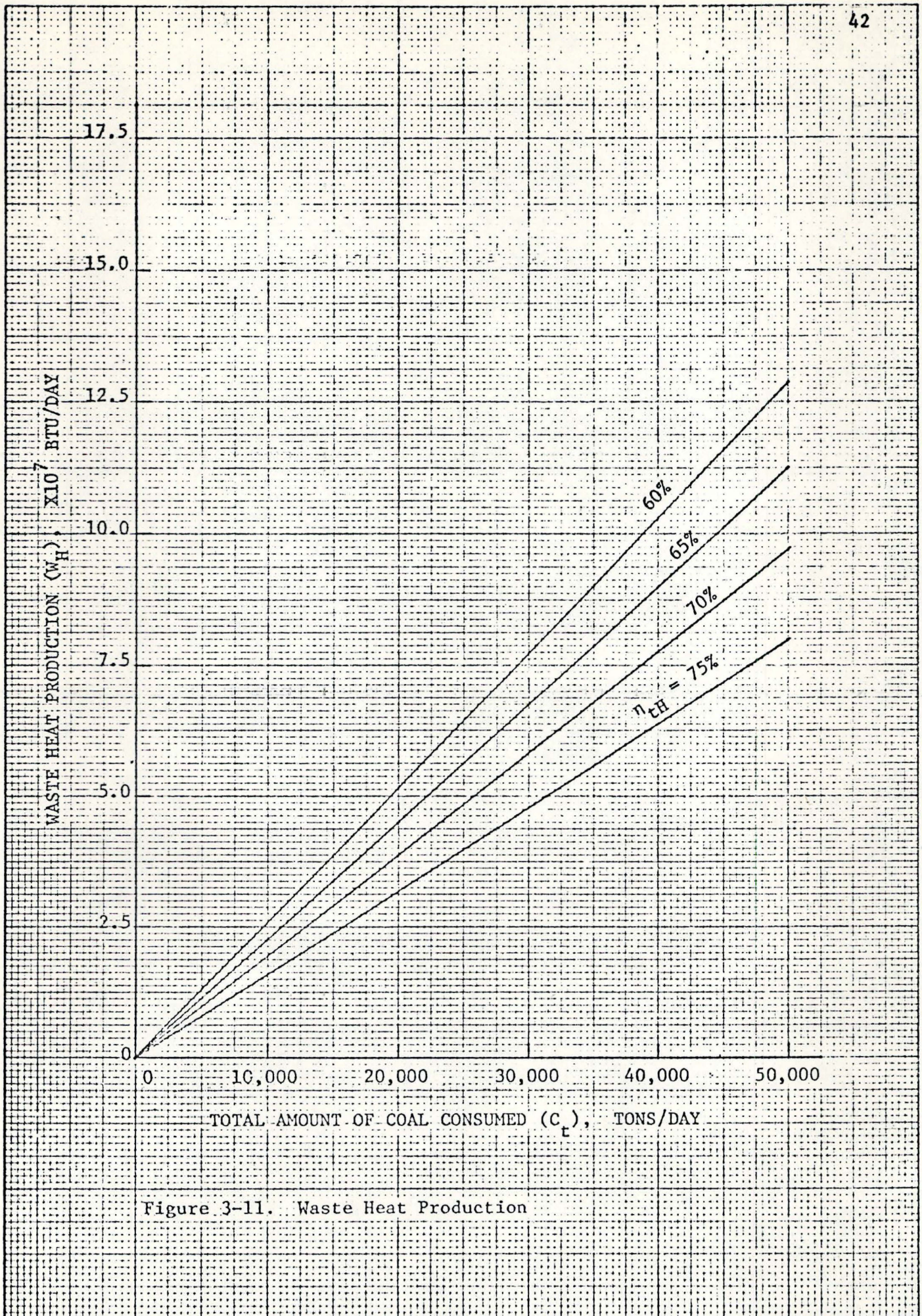

Figure 3-11. Waste Heat Production

3.4 Sample Calculations

A new 250 MMSCFD (million standard cubic feet of gas per day) gasification plant is to be constructed in North Dakota using North Dakota lignite. It is estimated the plant will be in operation 90% of the time (F_o). The thermal efficiency of the plant is 67.7%

The lignite has been analyzed and has the following characteristics:

Proximate Analysis		Ultimate Analysis	
Moisture	38.56%	Hydrogen	6.97%
Volatile Matter	27.03%	Carbon	39.05%
Fixed Carbon	27.57%	Nitrogen	.40%
Ash	6.84%	Oxygen	45.90%
HHUC	6456 BTU/lbm	Sulfur	.80%
		Chlorine	.04%
		Ash	6.84%

Estimate the amounts of natural resources needed and significant byproducts produced by the plant.

Coal Consumption

The amount of raw coal used in the gasifier train can be found from equation 1. With an operation factor (F_o) of 0.9 and a plant size (S_p) of 250 MMSCFD, the total coal consumed is:

$$C_g = 113.3\ (.9)\ (250) = 25{,}500 \text{ tons/day.}$$

The amount of coal consumed by the power plant is found from equation 2.

$$C_p = 3.42\ (250)\ (.9) = 770 \text{ tons/day.}$$

The amount of coal consumed in producing steam is found from equation 3.

$$C_s = .236\ (24{,}000)\ (.9) = 5098 \text{ tons/day.}$$

The total amount of coal consumed is found from equation 4.

$$C_t = 25{,}500 + 770 + 5098 = 31{,}368 \text{ tons/day.}$$

Water Consumption

From equation 7 the net water consumption can be found.

$$W_c = 239\ (250)\ (.9) = 53{,}775 \text{ tons/day.}$$

Oxygen Consumption

From equation 5 the amount of oxygen consumed can be found.

$$O_2 = .126\ (61.9)\ (250)\ (.9) = 1754 \text{ tons/day.}$$

Ash Production

Knowing the percentage of ash in the coal and the total coal consumption, the amount of ash produced is from equation 8.

$$A_p = .0684\ (31{,}368) = 2145 \text{ tons/day.}$$

Petroleum Byproduct Production

Knowing the amount of steam, oxygen, and coal consumed in the gasifiers, the amount of petroleum byproducts produced can be found from equation 10.

$$P_B = .0286\ (56{,}000) = 1602 \text{ tons/day.}$$

Sulfur Vented to the Atmosphere

Knowing the percent of sulfur in the coal is 0.8 and that 28,000

tons/day of coal are consumed in the gasifier train, the amount of sulfur vented to the atmosphere can be found from equation 11.

$$S_A = .01\ (.008)\ (28{,}000) = 2.24 \text{ tons/day.}$$

Sulfur Recovered

Again knowing the percent of sulfur in the coal and the amount of coal consumed in the gasifier train, the amount of sulfur recovered can be found from equation 12.

$$S_{RC} = .592\ (.008)\ (28{,}000) = 132 \text{ tons/day.}$$

Waste Heat Produced

Knowing the total coal consumption is 31,368 tons/day, the lower heating value of the coal is 6456 BTU/lbm and that overall plant thermal efficiency is 67.7%, the amount of waste heat produced can be found from equation 13.

$$W_H = 6456\ (31{,}368)\ (1-.677) = 6.54 \times 10^7 \text{ BTU/day.}$$

4. USER'S GUIDE OF DISPERSION PROGRAMS

The United State Government through the offices of the Environmental Protection Agency at Research Triangle Park, North Carolina, has provided a series of six computer programs on a single computer tape. The tape is called UNAMAP (Users Network of Applied Modeling of Air Pollution) and consists of six programs. Of these six programs three are of particular use to the study of short term air pollution from single and multiple point sources. The three programs that predict downwind concentrations of air pollutants from single and multiple sources are PTDIS (Point Distance), PTMAX (Point Maximum), and PTMTP (Multiple Points).

The following paragraphs give a description of the programs PTDIS, PTMAX, and PTMTP. A brief abstract and introduction will be given, followed by a description of the form of output given. A list of the program limitations and a list of the assumptions of the applicable mathematical model will also be given. A description of the data cards necessary for running the program will then be given. Appendix A contains an example of decks set up for each program. Appendix B contains several examples of program output.

4.1 PTDIS

The first program to be described is PTDIS. PTDIS calculates downwind ground level concentrations for various downwind distances for the input meteorological conditions. Only an individual source can be considered. Inputs to the program consist of information of the source and information on the meteorological conditions to be

considered. Primary output of the program consists of a table with height of emission and concentration given for each downwind distance. Also included in this table but not frequently needed are the values of the dispersion parameter sigma Y and sigma Z for each distance and also a relative concentration normalized for wind speed and source strength commonly called Xu/Q. An optional feature of the program allows the user to enter a value of concentration to be used for the determination of half-width of isopleth. For each distance if the concentration exceeds the stated isopleth value the half-width of an isopleth will be determined. Also, this half-width will be compared in the form of a ratio to the half-width of a sector of given angular size in terms of degrees. The user is also given the option of either specifying effective height of emission or having it calculated using Briggs' plume rise methods.

The program allows the user to investigate various atmospheric conditions and stack physical paramters that will result in maximum downwind ground level concentrations. The results can be used to aid in the design of stacks that along with the prevalent meteorological conditions of the area will not result in the violation of local, state, or federal air pollution regulations. The required air pollution control equipment effectiveness may also be studied.

PTDIS determines the concentration at ground level from a single point source using a steady-state Gaussian model. The computations used are similar to those shown in the Workbook of Atmospheric Dispersion Estimates [17]. The dispersion parameter values are also those given in Figures 3-2 and 3-3 of this workbook.

The program gives the user the option of specifying two forms of output. The user may obtain an output that lists in tabular form various concentration parameters for each of the specified downwind distances. The second form of output includes both the concentration parameter table and a second table that gives parameters relative to specified isopleth values at each of the specified downwind distances. The user also has the option of specifying as input the stack gas volume flow and the effective plume height or having the program calculate these values.

If the user selects to have the output consist only of the concentration parameter table, and he has the program calculate both the stack gas volume flow and the plume rise, the output will take the following form. First, input data is printed on two lines. The first line contains the specified wind speed, stability class, height of mixing, and ambient air temperature. The second line contains the specified emission rate, physical height of the stack, stack gas temperature, stack gas velocity, stack diameter, the calculated stack gas volume flow, the buoyancy flux, and the calculated height of the plume rise. After the input data is printed the concentration parameter table is printed. This table consists of eight columns. The first column lists the specified downwind distances, the second lists the effective height of the plume, the third lists the concentration at ground level of the air pollutant, the fourth lists the horizontal dispersion parameter sigma Y, the fifth lists the vertical dispersion parameter sigma Z, the sixth lists the relative concentration normalized for wind speed and source strength, the seventh

lists a loop counter labeled MDUM, and the eighth lists a loop counter labeled ANDUM. Each of the second through eighth columns corresponds to the first column of specified downwind distances.

If the user selects to have the output consist of both the concentration parameter table and the isopleth table and he selects to have the program calculate both the volume flow and the plume rise, the output takes the following form. The input data and the concentration table is printed as described for the first case. Following the concentration parameter table the isopleth table is printed. Above the isopleth table a single line containing the specified values of the isopleths is printed. The isopleth table consists of 17 columns. The first column contains the specified downwind distances. The number 2, 4, 6, 8, 10, 12, 14, and 16 columns contain the half-width distances to the specified isopleth values at each of the specified distances. This half-width distance is the distance from the specified downwind distance to a point at which the specified isopleth value (concentration) occurs. The distance is measured perpendicular to a line from the source to the specified downwind distance. The number 3, 5, 7, 9, 11, 13, 15, and 17 columns contain a ratio of the half-width of the isopleth to the half-width of a sector of a specified angle at the specified downwind distance.

For either of the two types of output the user may select to specify either the volume flow and/or the plume rise. Specifying either of these parameters will not change the form of the output. If the volume flow is specified the specified value rather than a calculated value is printed in the input data line. If the plume rise

is specified the specified value rather than a calculated value is printed in the effective height column of the downwind concentration parameter table. The second line of input data is also altered. This line will then contain only the emission rate and the specified plume height. Some examples of the program output are given in Appendix B1.

Some limitations of the program are listed below.

1. Concentrations derived from these calculations can be considered to be valid for averaging times from ten minutes to an hour. The meteorological input must also be valid for these averaging times.

2. Although the computational system will yield numerical values for effective plume heights of above 1,000 meters, any computations performed for plume heights of greater than 300 or 400 meters should be considered with a certain amount of skepticism.

3. If the calculated plume height exceeds the input mixing height the downwind ground level concentrations will be calculated to be zero. If this condition occurs it will be necessary to specify the plume height at some level lower than the mixing height or raise the height of mixing to a level above the calculated plume rise.

The assumptions of the mathematical model are listed below.

1. The single meteorological condition as defined by Pasquill's stability types A through F is assumed to occur from ground level to the mixing height.

2. The single wind speed used is assumed to be constant from the top of the stack through the layer where plume rise occurs.

3. The effect of a definite limit to vertical dispersion or mixing height is included in the computations. It is assumed that complete eddy reflection occurs at this barrier.

4. The concept of a mixing height is not employed for stabilities E or F.

5. There are no topographic obstructions in the vicinity of the source and that the source is in an area of either flat or gently rolling terrain.

6. No consideration of the possibility of aerodynamic downwash is included.

Computer Card Deck Set-Up

The first card in the deck will be the Job card and will be followed by six JCL (Job Control Language) cards. The program is stored on a magnetic tape and some of the JCL cards are used to access the proper tape and file. The data cards are placed after the JCL cards. An example of deck set-up for PTDIS including JCL and data cards is given in Appendix A1.

The first type of data card is a single title card used to print a heading on the first page of output. Columns 1-80 may be used on the card and any alphanumeric character may be used.

The second type of data card is a single control card. This card inputs to the program the number of distances from the source to be considered. It also inputs to the program whether isopleths should be considered and whether the effective emission height will be specified or is to be calculated. It also inputs the number of isopleths if any and the wind segment size in degrees.

The third type of data card is the distance card. This card inputs to the program in kilometers the distances from the source at which the ground level concentrations should be calculated. From 1 to 7 cards may be used with up to 8 distances placed on each card.

The fourth type of data card is a single isopleth card. This card is read only if the control card specifies that isopleths should be considered. A maximum of 8 isopleths can be inputted to the program by this card. The units of the isopleths are grams per cubic meter.

The fifth type of data card is a single source card. If the effective height of emission is to be calculated this card will input to the program the source strength in grams per second, the height of the stack in meters, the stack gas temperature in degrees Kelvin, the stack gas velocity in meters per second, the diameter of the stack in meters and the volume flow in cubic meters per second. The volume flow can be omitted and the diameter and the stack gas velocity will be used to calculate the volume flow. If the volume flow is given it is assumed correct and the stack gas velocity and the diameter are not used.

If the effective height of emission is specified, the previous card is omitted and a different source card is used. This source card inputs to the program the source strength in grams per second and the effective height of emission in meters.

The sixth type of data card is the meteorology card. Any number of cards can be used, but the last card must be blank for control. The meteorology cards input to the program the wind speed in meters per second, the stability class (dimensionless), the mixing height

in meters and the ambient air surface temperature in degrees Kelvin. The temperature can be omitted from the card and the program will use a value of 293°K.

The seventh and last type of data card is a single control card. This card is used to control the program flow. Either a zero, one, or two is placed in column 1. A zero indicates that the program is to call exit, a one is used to redefine controls, and a two is used to tell the program to read new source information.

Following the data cards the blue card is placed and is the last card in the deck.

4.2 PTMAX

A second program similar to PTDIS but less complicated is PTMAX. PTMAX produces an analysis of maximum concentration as the function of wind speed and stability. A separate analysis is made for each individual stack. This program is useful in determining what combinations of wind speed and stability produce maximum concentrations. The program computes maximum ground level concentrations for various wind speeds ranging from 0.5 to 20.0 meters per second for each of the six stability classes as defined by Pasquill. The program computes maximum ground level concentrations for a range of wind speeds for which a particular stability can occur, i.e., a Pasquill C stability is calculated only for a range of 2.0 to 15.0 meters per second. All stabilities are automatically considered.

Input to the program consists of ambient air temperature and characteristics of the source such as emission rate, physical stack height, and stack gas temperature. Either the stack gas volume flow

or both the stack gas velocity and inside diameter at the top are also required. Outputs of the program consist of effective height of emission, maximum ground level concentration, and distance of maximum concentration for each condition of stability and wind speed.

A final plume rise is added to the physical height of the stack and this total height is considered the effective height of emission. The effective height of emission is used to determine both the maximum concentration and the distance to maximum concentration. The plume rise is calculated by methods suggested by Briggs, and the plume dispersion calculations are performed according to a steady-state Gaussian model. The calculations are performed according to the Workbook of Atmospheric Dispersion Estimates. The dispersion parameter values used for the horizontal dispersion coefficient, sigma Y, and the vertical dispersion coefficient, sigma Z, are those given in Figures 3-2 and 3-3 of the workbook.

PTMAX outputs data in tabular form. Before the output table is printed input data is printed on two lines. The first line contains the specified emission rate, the physical height of the stack, the stack gas temperature, and the stack gas velocity. The second line contains the diameter of the stack and the volume flow whether specified or calculated. Above the output table a single row containing wind speeds from 0.5 to 20.0 meters per second is printed. The first column of the output table contains atmospheric stabilities 1 through 6. For each stability and wind speed the maximum concentration, the downwind distance to the maximum concentration, and the effective height of emission at the point of maximum concentration are printed. No output

is printed for wind speeds at which a particular stability is not valid. For an example, a class 3 stability would exist only at wind speeds from 2.0 to 15.0 meters per second so no data is printed for wind speeds less than 2.0 or greater than 15.0 meters per second. The output data will contain warning subscripts if certain conditions are exceeded. A subscript 1 indicates that the distance to the point of maximum concentration is so great that the same stability is not likely to persist long enough for the plume to travel this far. A subscript 2 warns that the plume is of sufficient height so that extreme caution should be used in interpreting this computation as the given stability type may not exist to the calculated height. Also, wind speed variations with height may exert a dominating influence. A subscript 3 warns that the point of maximum concentration is greater than 100 kilometers from the source and no computations will be attempted. An example of the output is given in Appendix B2.

The assumptions that are applicable to the mathematical model used in making the calculations are listed below.

1. The given wind speed occurs at the stack top and is constant through the layer where the plume rise occurs.

2. The given stability occurs from ground level to well above the top of the plume.

3. Any limit to vertical mixing occurs far enough above the top of the plume so that is has no influence upon the maximum concentration.

4. There are no topographic obstructions in the vicinity of the source and the terrain is either flat or gently rolling.

Some limitations of the program are listed below.

1. The calculations are not valid if aerodynamic downwash around buildings in the vicinity of the source affects the plume emitted from the stack.

2. Calculations are for a single source. If multiple stacks exist the program can be applied to an individual stack, but it cannot give the maximum concentrations of the combination of the stacks.

Computer Card Deck Set-Up

The deck set-up for PTMAX is rather simple since only two data cards are required. Following the Job card, 6 JCL cards are required as shown in Appendix A2. Following the JCL cards the two data cards are placed.

The first type of data card is a single title card. This card is used to put a heading at the top of the output for each source considered. Any alphanumeric character may be used in columns 1 through 80.

The second type of data card is a single source card. This card inputs to the program the source strength in grams per second, the physical height of the stack in meters, the stack gas temperature in degrees Kelvin, the stack gas velocity in meters per second, the diameter of the stack in meters, and the volume flow of the stack in cubic meters per second. The volume flow can be omitted from the card and the velocity and diameter are used to calculate a volume flow. If the volume flow is given it is assumed correct and the diameter and the stack gas velocity are not used. Any number of sets consisting of one title card and one source card can be used. The last set must

be followed by two blank cards for control.

The last card in the deck will be the blue card. An example of deck set-up for PTMAX is given in Appendix A2.

4.3 PTMTP

The third program to be described is PTMTP. PTMTP calculates concentrations at up to 30 receptors whose locations are specified from up to 25 point sources. The receptors can be placed at ground level or at any height above the ground. Concentrations for a number of hours up to 24 can be estimated, and an average concentration over this time period is calculated. Both partial concentrations and total concentrations can be included in the output. This allows the user to predict the contribution of each source to the total concentration at each of the receptor points. The total concentration is also predicted. Inputs to the program consist of number of and location in coordinates of each source. For each source the emission rate, stack physical height, stack gas temperature, stack gas velocity, stack diameter, and the volume flow are also inputted. The number of receptors and the location of and height above the ground for each receptor is also required. Meteorological information inputted to the program consists of wind direction, wind speed, stability class, mixing height, and the ambient air temperature and pressure. Output of the program consists of partial concentrations at each receptor from each source for each hour considered. Total concentrations at each receptor are also outputted. Average partial and total concentrations are also given for the total number of hours considered. For the partial

concentrations a final plume height is also calculated. If the downwind distance is closer than the distance to the final rise, the plume rise for this distance is calculated.

The calculations are made according to a Gaussian plume model. These computations can be performed according to the Workbook of Atmospheric Dispersion Estimates. The dispersion parameter values used for the horizontal dispersion coefficient, sigma Y, and the vertical dispersion coefficient, sigma Z, are those given in Figures 3-2 and 3-3 of the workbook. Calculations for each hour are made by considering each source-receptor pair. For each source-receptor pair the downwind and crosswind distances are determined. The plume rise is calculated according to Briggs' method.

The output of PTMTP may be specified in two forms. The user may specify that the output data include both total and partial concentration data from one or more point sources or he may eliminate the partial concentration data from the output.

If both partial and total concentration data is required the output will take the following form. First, the source data is printed for each specified source. The data consists of the specified source strength, the physical height of the stack, the stack gas temperature, the stack gas velocity, the stack diameter, the volume flow if specified, and the coordinates of the source. Next, the coordinates of the specified receptors are printed. The specified meteorology data is printed next. The data includes the direction of the wind, the wind speed, the atmospheric stability type, the mixing height, the ambient air temperature, and the ambient air pressure. Following the

meteorological data the partial concentration table is printed. This data is in tabular form. The table contains the calculated partial concentrations at each of the specified receptors due to each individual source. Next, a table consisting of total concentration data is printed. This table contains the calculated total concentrations at each of the specified receptors from the specified sources. Additional tables will be printed for each of the additional meteorological conditions specified. Each meteorological condition is assumed valid for a one hour averaging period. The last output to be printed is two tables that contain an average of partial and total concentration for all of the specified meteorological conditions.

If the partial concentrations are not requested the output is the same except that the partial concentration tables are not included. An example of the output is given in Appendix B3.

The assumptions of the mathematical model used in the calculations are given below.

1. Meteorological conditions are steady-state for each hour.

2. The sources and receptors exist in either flat or gently rolling terrain.

3. The wind speed and direction are applicable throughout the layer of plume rise. No wind direction shear or wind speed shear occurs.

4. The given stability exists from ground level to well above the tope of the plume.

The limitation of the program is listed below.

1. The calculations are invalid if the plumes are affected by aerodynamic downwash due to building turbulence.

Computer Card Deck Set-Up

The deck set-up required for PTMTP is similar to that required for PTDIS and PTMAX. Following the Job card 6 JCL cards are required. An example of the necessary JCL card is given in Appendix A3. Following the JCL cards the data cards are placed.

The first type of data card is a single title card. This card is used to place a heading at the top of the first page of output. Any alphanumeric character may be placed in columns 1-80.

The second type of data card is a single control card. Either a 1 or 2 is placed in column 10. If a 1 is used the partial concentrations will be printed, and if a 2 is used the partial concentrations will not be printed.

The third type of data card is the source card. Up to 26 source cards may be included in the deck. One source card will be included for each source to be considered. The source card inputs to the program the source strength in grams per second, the stack physical height in meters, the stack gas temperature in degrees Kelvin, the stack gas velocity in meters per second, the stack diameter in meters, and the volume flow in cubic meters per second. The volume flow can be omitted from the card and the stack gas velocity and diameter will be used to calculate the volume flow. If the volume flow is given it is assumed correct and the stack gas velocity and diameter are not used. This card inputs to the program the R and S coordinates in kilometers. The sources are placed relative to a cartesian coordinate system. The R coordinate corresponds to the abcissa of the system and the S coordinates corresponds to the ordinate of the system; therefore, a

source placed at R = 1.0 and S = 2.0 would be considered to be 1 kilometer east and 2 kilometers north of the origin.

The fourth type of data card is the receptor card. Up to 31 of these cards can be included in the deck, one for each receptor location. This card inputs to the program the R and S coordinates in kilometers of the receptor. It also inputs to the program the height in meters of the receptor above the ground. The same cartesian system is applied to both the sources and the receptors. No receptor may be placed at the origin of the system.

The fifth type of data card is the meteorology card. One meteorology card is used for each hour to be considered. This card inputs to the program the wind direction in degrees, the wind speed in meters per second, the stability class (dimensionless), the mixing height in meters, the ambient air surface temperature in degrees Kelvin, and the ambient air pressure in millibars. The temperature and/or the pressure can be left blank and default values of T = 293°K and P = 960 mb will be used.

Following the last meteorological card a blank card is placed for control. It is followed by the blue card which is the last card of the program deck. An example of deck set-up for PTMTP is given in Appendix B3.

5. ESTIMATES OF AIR POLLUTANT CONCENTRATIONS (POWER GENERATING PLANTS)

The previous chapters of this thesis may now be used to aid in the estimation of short term air pollution from coal fired steam generating plants. The power plant to be studied is a general one, but in keeping with the theme of this thesis parameters common to North Dakota lignite coal and North Dakota meteorology will be used.

5.1 Federal and State Air Quality Standards

The Federal Government and the State of North Dakota have established ambient air quality standards. The Federal Government and the State of North Dakota have also established regulations pertaining to the emission of air pollutants from stationary sources.

Federal ambient air quality standards are divided into primary and secondary standards. Primary air quality standards define the relative air quality levels judged necessary, with an adequate safety margin, to protect the public health. Secondary air quality standards are those specifically concerned with protecting the public welfare, i.e., material, vegetation, visibility, etc., from any know adverse effects of a pollutant. Federal primary and secondary air quality standards for suspended particulate matter, sulfur oxides, and nitrogen oxides are listed in Table 5-1.

Ambient air quality standards for the State of North Dakota are listed in Table 5-2. Degradation of the ambient air having a higher quality than the state standards is restricted unless it is demonstrated that a change in quality is justifiable and will not violate

Table 5-1 Federal Primary and Secondary Ambient Air Quality Standards

Pollutant	Averaging Time	Primary Standard	Secondary Standard
Sulfur Dioxide	Annual Avg.	80 $\mu g/m^3$ (.03ppm)	
	24-Hour	365 $\mu g/m^3$ (.14ppm)	
	3-Hour		1300 $\mu g/m^3$ (0.5ppm)*
Particulate Matter	Annual Avg.	75 $\mu g/m^3$	60 $\mu g/m^3$
	24-Hour	260 $\mu g/m^3$*	150 $\mu g/m^3$
Nitrogen Dioxide	Annual Avg.	100 $\mu g/m^3$ (.05ppm)	100 $\mu g/m^3$ (.05ppm)

*Not to be exceeded more than once a year

ppm-parts per million

$\mu g/m^3$-micrograms per cubic meter

Source: Code of Federal Regulations, Part 50, pp. 3-29, 1974

Table 5-2 North Dakota Ambient Air Quality Standards

Pollutant	Averaging Time	Standard (Maximum Permissible Concentration)
Sulfur Dioxide	Annual Avg.	60 $\mu g/m^3$ (0.02ppm)
	24-Hour	260 $\mu g/m^3$ (0.10ppm)
	1-Hour	715 $\mu g/m^3$ (0.28ppm)
Nitrogen Dioxide	Annual Avg.	100 $\mu g/m^3$ (0.05ppm)
	1-Hour	200 $\mu g/m^3$ (0.10ppm)*

*Not to be exceeded over 1 percent of the time in any 3-month period

$\mu g/m^3$-micrograms per cubic meter

ppm-parts per million

Source: North Dakota Air Pollution Control Regulations, Regulation 23-25.

North Dakota's air quality guidelines. These guidelines are:

a) The health of even sensitive or susceptible segments of the population will not be adversely affected;

b) concentrations of pollutants will not cause public nuisance or annoyance;

c) significant damage to animals, ornamental plants, forest and agricultural crops will not occur;

d) visibility will not be significantly reduced;

e) metals or other materials will not be significantly corroded or damaged;

f) fabrics will not be soiled, deteriorated, or their colors affected; and

g) natural scenery will not be obscured.

The Federal and State emission regulations are given in Table 5-3. The Federal regulations pertain to the emissions from steam generators as defined by the EPA's New Source Performance Standards (NSPS).

Table 5-3 Federal and State Emission Regulations

Pollutant	Federal	North Dakota
Particulate	0.1 $lb/10^6$ BTU	0.18 $lb/10^6$ BTU
SO_2	1.2 $lb/10^6$ BTU	3 $lb/10^6$ BTU
NO_x	0.7 $lb/10^6$ BTU	

5.2 Emission Rate Calculations

Emission rates from a hypothetical power plant can be estimated

by the methods of Chapter 2 and the results compared to the Federal and State regulations. The power plant to be studied is assumed to produce 600 megawatts of electrical power, and will consume North Dakota lignite coal. The coal has been analyzed and has the following characteristics:

moisture - 38.6%

volatile matter - 27.0%

fixed carbon - 27.6%

ash - 6.8%

sulfur - 0.8%

LHV 6456 BTU/lbm.

The methods described in Chapter 2 were used to estimate the emission rates. The calculated emission rates and the physical parameters of the stack are given in Table 5-4. The calculated emission rates given in Table 5-4 were converted to the units given in the Federal and State regulations. With no scrubber SO_2 emissions (2.36 lb/10^6BTU) were found to exceed the Federal standards. The results indicate that a scrubber system with an efficiency of approximately .50 would be required to satisfy the Federal regulations. Scrubber efficiency is defined as the amount of air pollutant removed from the effluents divided by the total amount of air pollutant contained in the effluents.

Assuming that precipitators remove 98% of the particulate matter, it is found that the plant will emit 0.161 lb/10^6 BTU of particulate matter to the atmosphere. This emission rate exceeds Federal standards. The results indicate that a precipitator efficiency of approximately .993 will be required to satisfy the Federal standards.

The methods of Chapter 2 were also used to estimate the emissions

Table 5-4 Emission Data

Pollutant	Emission Rate (grams/sec)	Stack Gas Temperature (^{o}Kelvin)	Stack Gas Velocity (m/sec)	Stack Diameter (m)	Volume Flow (m^3/sec)
SO_2 (No Scrubber)	1605.0	431	27.45	8.24	1463.8
SO_2 (Scrubber $\mu_{+H} = 0.70$)	481.5	431	27.45	8.24	1463.8
SO_2 (Scrubber $\mu_{+H} = 0.80$)	321.0	431	27.45	8.24	1463.8
SO_2 (Scrubber $\mu_{+H} = 0.90$)	160.5	431	27.45	8.24	1463.8
Particulate (Precipitator $\mu_{+H} = 0.98$)	112.4	431	27.45	8.24	1463.8
NO_x (No Scrubber)	432.5	431	27.45	8.24	1463.8

of nitrogen oxides. The calculations show that 0.62 lbs/10^6BTU of nitrogen oxides will be emitted to the atmosphere. This emission rate does not exceed either the Federal or State standards.

5.3 Meteorological Conditions

In order to estimate downwind ground level concentrations of air pollutants from stationary sources it is necessary to examine the meteorological conditions of the planned plant site. Since this report concerns a general type of power plant to be built somewhere in western North Dakota, a brief examination of typical meteorological conditions of western North Dakota will be given. The type of meteorological conditions that are of greatest concern are those that will cause the largest ground level concentrations of pollutants and those that occur with the largest frequency.

Meteorological data is available from several cities of western North Dakota. They are: Bismark, Dickinson, Williston, and Minot. The meteorological data that will affect the dispersion of air pollutants includes: ambient air temperature, wind direction and velocity, stability class, and the atmosphere mixing height.

Wind Speed and Direction

Wind speed and wind direction data from western North Dakota indicates that wind generally blows from a west-east direction to a northwest-southeast direction, and that the average wind speed is between 10.0 and 13.0 mph.

Stability Class

The stability of the atmosphere is best estimated by measuring

the vertical temperature profile. A rapid decrease in temperature with height, a superadiabatic lapse rate, is associated with very unstable conditions which are generally favorable to pollutant dispersion. An isothermal condition and a near superadiabatic lapse rate (DT/DZ=-1°C/100 m) correspond to neutral stability conditions. An increase in temperature with height, an inversion, is responsible for a stable atmospheric layer where atmospheric diffusion is inhibited.

Pasquill (1961) classified the range of atmospheric stability conditions into six categories given below:

A - very unstable

B - unstable

C - slightly stable

D - neutral

E - stable

F - very stable.

Table 5-5 gives a frequency of occurrence of the various stabilities for data collected at Dickinson, North Dakota. The meteorological data that is presented in this and other meteorological tables is taken from an Interim Report to the Natural Gas Pipeline Company on the Meteorological and Air Quality Aspects of a Proposed Coal Gasification Plant in Dunn County, North Dakota [14].

Table 5-5 Percent Frequency of Stability Classes, August - October and Annual Frequency (1960-1964), Dickinson, North Dakota

Stability Class	August	September	October	Annual
A	1.0	0.1	0.2	0.5
B	4.8	2.0	1.1	2.1
C	11.3	6.0	5.0	6.3
D	54.7	65.1	65.7	69.9
E	18.0	17.3	18.5	14.0
F	10.2	9.5	9.5	7.2

This data indicates that near neutral stabilities occur over 80% of the time during the months of August, September, and October. Extremes of the stabilities occur infrequently and the unstable conditions (classes A and B) occur only 2.6% of the time as an annual average.

Atmospheric Mixing Height

Mixing height is defined as the thickness of that atmospheric layer about the earth's surface within which vertical mixing is enhanced relative to the higher air layers. Holeworth's estimates (1972) of mean morning and afternoon mixing heights are given in Table 5-6.

Table 5-6 Mean Mixing Heights (Meters) in Western North Dakota

	Annual	Winter	Spring	Summer	Fall
Morning	300-400	300-400	400-500	300	300
Afternoon	1500-1600	600-1000	2000-2400	2000-3200	1400-2000

Low mixing heights will tend to increase ground level concentrations and very high mixing heights tend to decrease ground level concentrations. The lower mixing heights tend to occur in the morning hours and the higher mixing heights tend to occur in the afternoon. The variation of mixing height with seasons is also apparent from the table. The lowest seasonal mixing heights occur during the winter and the highest occur in the spring and summer.

Averaging Time

The averaging time is assumed valid for various periods of time depending on the stability class that is being considered. The valid averaging times for the various stability classes is given below.

Stability Class	Averaging Time
A	10 minutes
B	10 minutes
C	1 hour
D	3 hours
E	30 minutes
F	30 minutes

In order to make comparisons between estimated concentration levels and Federal and State regulations it is necessary to use a power law relationship to convert the estimated concentration levels. The relationship for the conversion is given as

$$X_2 = X_1 \left(\frac{t_2}{t_1}\right)^{-\beta}$$

where X_2 is the concentration estimate for sampling time t_2

X_1 is the concentration estimate for sampling time t_1

β is 0.44.

This power law relationship was suggested by the Northern Great Plains Research Program (1974) [14].

5.4 SO_2 Ground Level Concentrations

Sulfur dioxide constitutes the single largest air pollutant from a coal fired power generating plant. Therefore, SO_2 was used as a pollutant to investigate the effect of various atmospheric conditions and plant physical parameters on the estimated ground level concentrations. Atmospheric conditions investigated were: stability class, wind speed, and mixing height. Plant physical parameters investigated were stack height, use of multiple units, and use of SO_2 scrubbers.

Stability Class and Wind Speed

An estimation of maximum groud level SO_2 concentrations was made at various wind speeds and stability classes. The results are presented in Figure 5-1. The estimations were made with the use of the PTMAX program described in Chapter 4. The input parameters of the program are those given in Table 5-4 for SO_2 with no scrubber. The input stack height was 700 feet and an unlimited mixing height was assumed. The results indicate that the largest ground level concentrations occur at low windspeeds and very unstable atmospheric conditions. No results were obtained for the stable and very stable conditions since a limitation of the program was exceeded and it did not perform the calculations. The maximum calculated ground level concentration for stability class A was 275 $\mu g/m^3$. Using the power law relationship described previously it was found that

none of the investigated conditions would create ground level concentrations that would exceed either Federal or State standards for sulfur dioxide.

In addition to maximum ground level concentrations the PTMAX program also calculates the downwind distance to the maximum concentration and the effective plume height at the point of maximum concentration. This data is presented in Figures 5-2 and 5-3, respectively.

Mixing Layer Height

The mixing layer has a significant effect on maximum ground level concentrations. This effect was investigated with a series of computer runs using the PTDIS program. The results are plotted on Figure 5-4. The pollutant was assumed to be SO_2 emitted from a 700 foot stack with the physical parameters of Table 5-4. No scrubbing was assumed and a single stability class (C) was used. The mixing heights were varied from 400 to 2500 meters and the wind speeds were varied from 2.0 to 15.0 meters per second. The results indicate that at mixing heights greater than 1000 meters the maximum ground level concentrations are relatively insensitive to changes in the mixing height. Below 1000 meters changes in the mixing height have a significant effect on maximum ground level concentrations. This effect is more noticeable at lower wind speeds. At a mixing height of 400 meters and a wind speed of 2.0 meters per second the maximum ground level concentration for a 1-hour averaging time was found to be 1410 $\mu g/m^3$. This value exceeds the State standards. The results indicate that a scrubber with an efficiency of approximately 0.5 would have to be employed to avoid violating the State standards under these conditions.

Stack Height

One method of reducing ground level concentrations of air pollutants emitted from a stack is to raise the height of the stack. This method of reducing ground level concentrations was investigated with a series of PTDIS computer program runs. The results are plotted on Figure 5-5. The air pollutant was assumed to be SO_2. The physical parameters of the stack are those found in Table 5-4 for SO_2 with no scrubber. A stability class C, a wind speed of 5.0 meters per second, and a mixing height of 1500 meters were used on all runs. The stack heights were varied from 700 to 1100 feet. The results indicate that increasing the stack height from 700 to 1100 feet will reduce the maximum ground level concentration under the given atmospheric conditions from 81 $\mu g/m^3$ to 61 $\mu g/m^3$, assuming a 1-hour averaging time. Plots of the downwind concentrations for the various stack heights are presented on Figure 5-6, and isopleth plots for the various stack heights and input conditions are given in Figures 5-7 through 5-11.

Scrubber Efficiency

The previous estimations indicate that some removal of SO_2 from the effluents of the stack will be necessary in order to conform with Federal and State air pollution regulations. Scrubbers may be employed to remove SO_2 from the effluents. Several computer runs using the PTMAX program were made to investigate the effect of scrubber efficiency on maximum ground level concentrations for various stabilities and wind speeds. The results are plotted on Figure 5-12. Efficiencies of 0.70, 0.80, and 0.90 were assumed. A 700 foot stack was assumed, and the input

parameters used are those found in Table 5-4. The results indicate that removing 70% of the SO_2 from the effluents will reduce the maximum ground level concentrations by a like amount.

Multiple Units

The previous sections have assumed that only a single unit would be used to produce electrical power. In some cases it may be desirable to locate more than one unit at one site. In order to investigate the effect on air quality by placing more than one unit at a particular site, the PTMTP program was utilized. Each unit was assumed to emit its waste products through one stack. The effect of 2, 3, and 4 units (each 600 mw) was investigated. The effect on the maximum ground level concentrations by changing the distance between the stacks was also investigated. The results are plotted on Figure 5-13. The stacks were assumed to be 700 feet high, and the distance between the stacks was assumed to be 30 meters and 100 meters. A stability class C and a 1500 meter mixing height was assumed. The results indicate that increasing the units by 4 will nearly quadruple the ground level concentrations. One unit at a stability class C, unlimited mixing height, and a 10 m/sec wind speed results in a maximum ground level concentration of 85 $\mu g/m^3$, and 4 units with a 30 meter spacing and the same atmospheric conditions, but with a 1500 meter mixing height, will result in a maximum ground level concentration of 390 $\mu g/m^3$. The effect of varying the distance between the stacks from 30 meters to 100 meters was not found too be large. With 4 units and a wind speed of 15.0 m/sec the maximum ground level concentration was reduced from 390 to 376 $\mu g/m^3$ when the distance between the

stacks was changed from 30 to 100 meters. The effect was smaller with 2 and 3 units.

5.5 NO_x and Particulate Ground Level Concentrations

In addition to SO_2 being emitted from the stack, oxides of nitrogen and particulate matter will be emitted from the stack. The PTMAX program was used to estimate the maximum ground level concentrations of NO_x and particulate matter for various stabilities and wind speeds. The results are plotted on Figures 5-14 and 5-15 for NO_x and particulate matter, respectively. A 700 foot stack and unlimited mixing was assumed. The input parameters for NO_x and particulates to the program are those found in Table 5-4. The results indicate that for the unlimited mixing condition neither the estimated ground level NO_x nor ground level particulate concentrations will exceed Federal or State regulations. Downwind plots of ground level concentrations for NO_x and particulate matter are given in Figures 5-16 and 5-17, respectively.

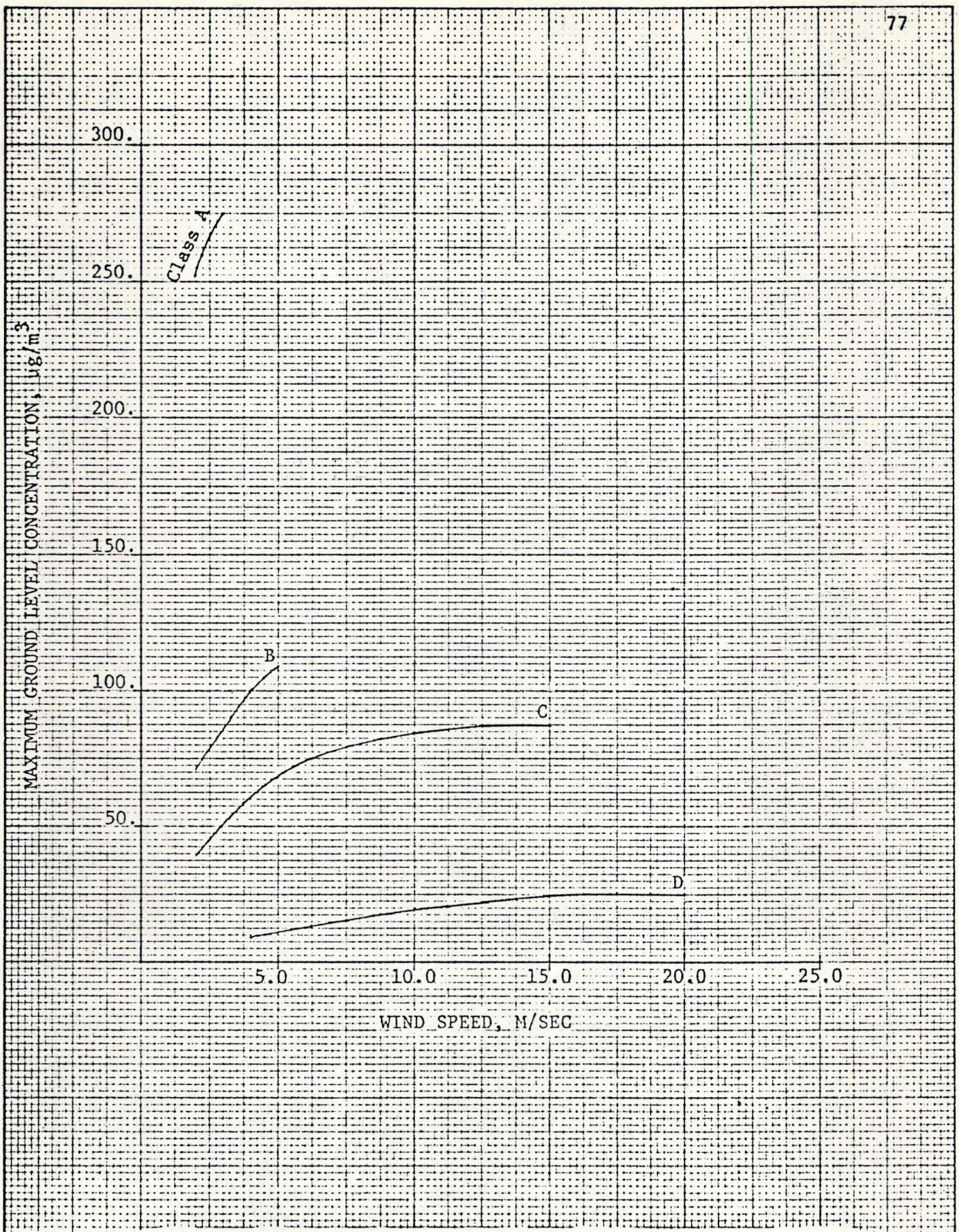

Figure 5-1. Maximum Ground Level SO_2 Concentrations for Different Wind Speeds and Stability Classes, 700 Foot Stack and Unlimited Mixing

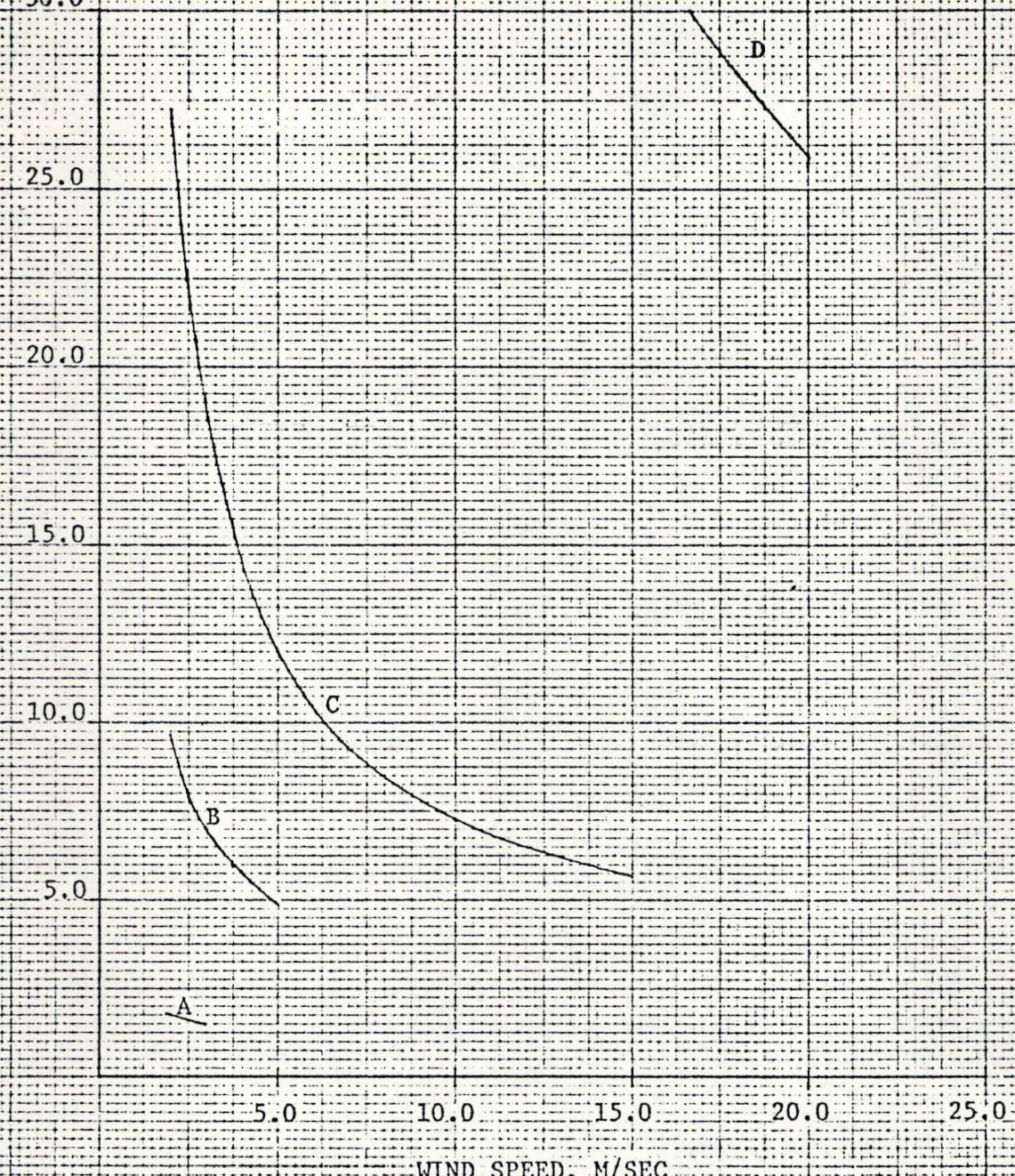

Figure 5-2. Distances to Maximum Concentrations for Different Wind Speeds and Stability Classes, 700 Foot Stack

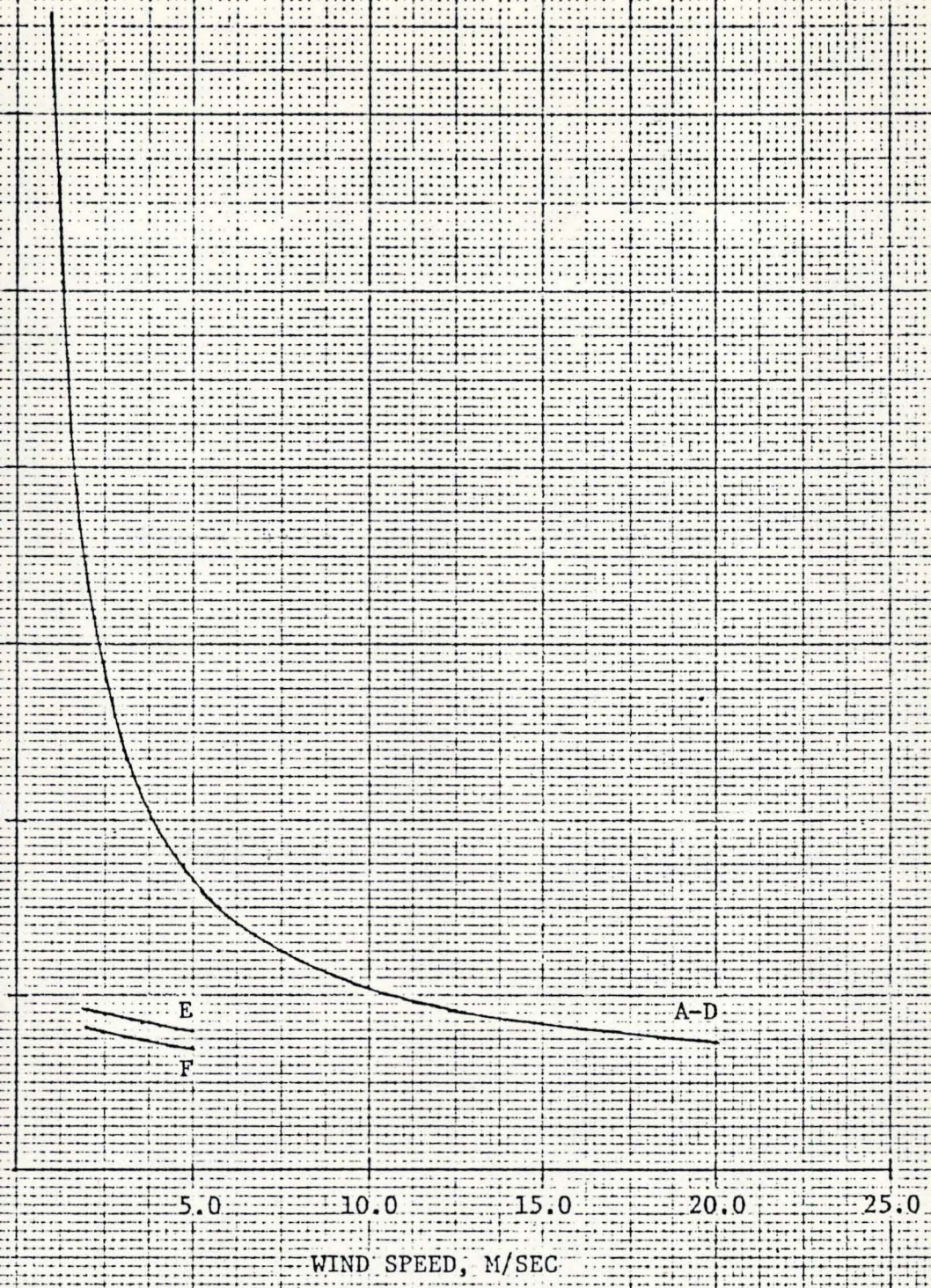

Figure 5-3. Effective Plume Height for Different Windspeeds and Stability Classes, 700 Foot Stack.

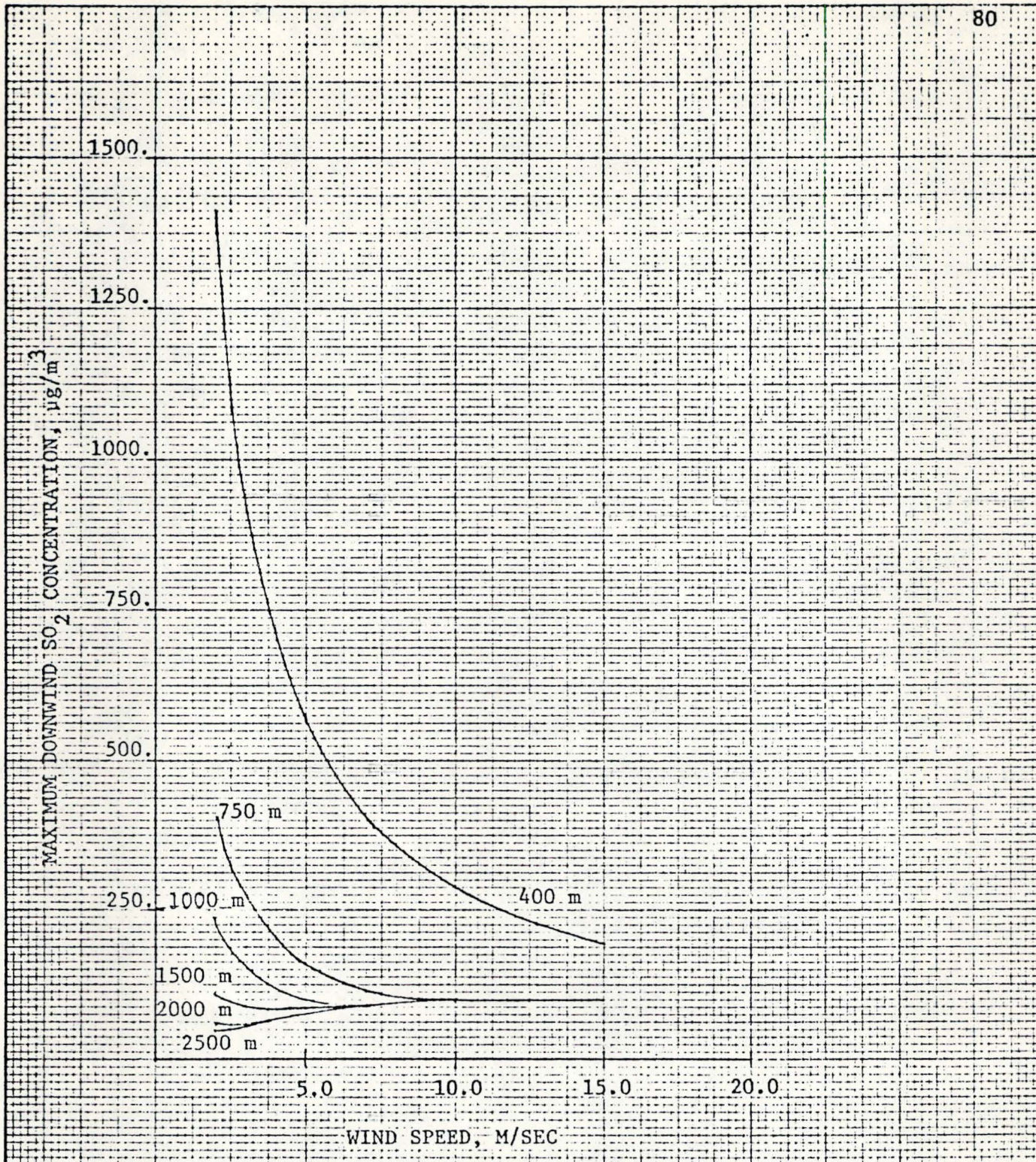

Figure 5-4. Effect of Mixing Height on Maximum Ground Level SO_2 Concentration, 700 Foot Stack and Stability Class C

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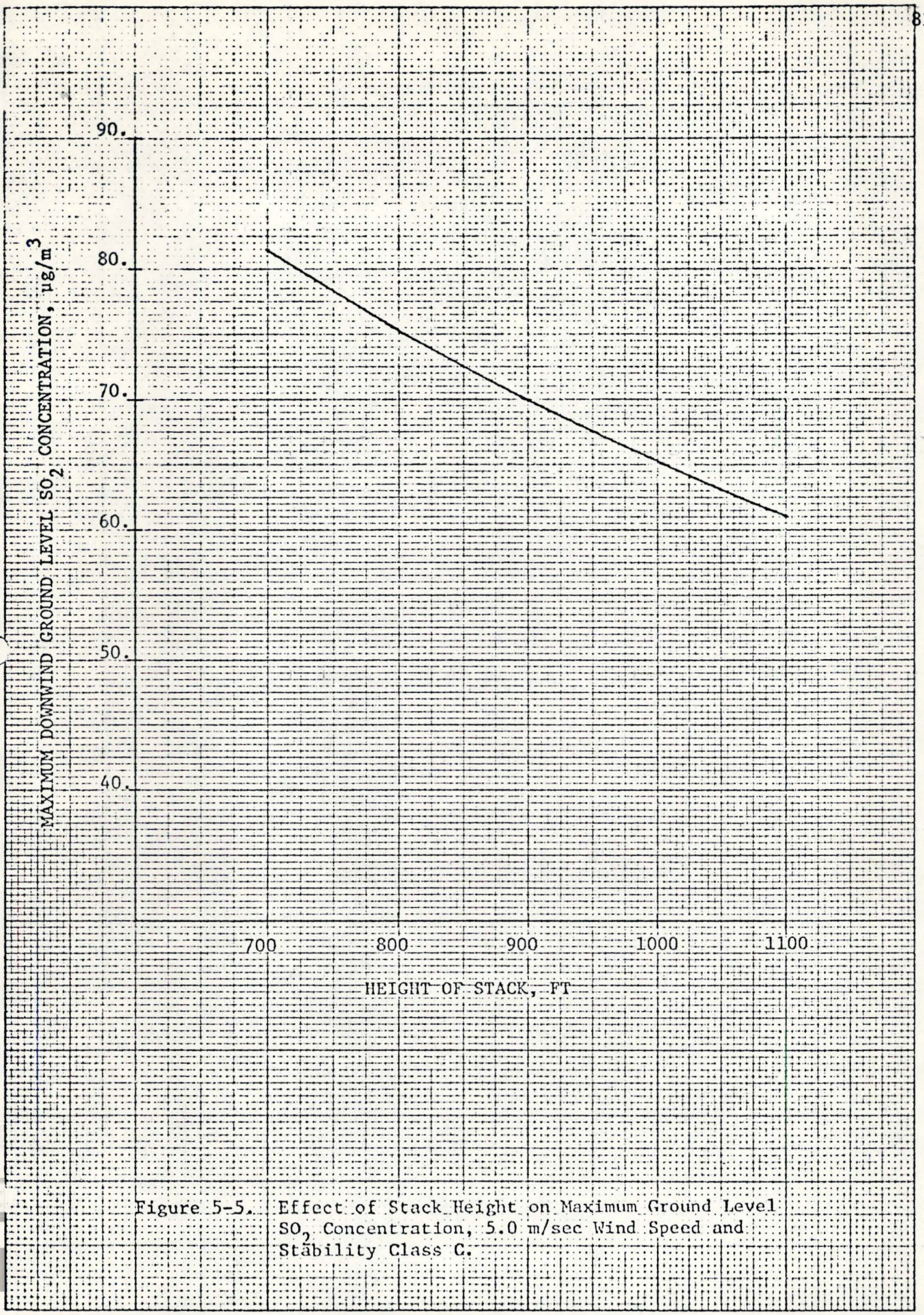

Figure 5-5. Effect of Stack Height on Maximum Ground Level SO_2 Concentration, 5.0 m/sec Wind Speed and Stability Class C.

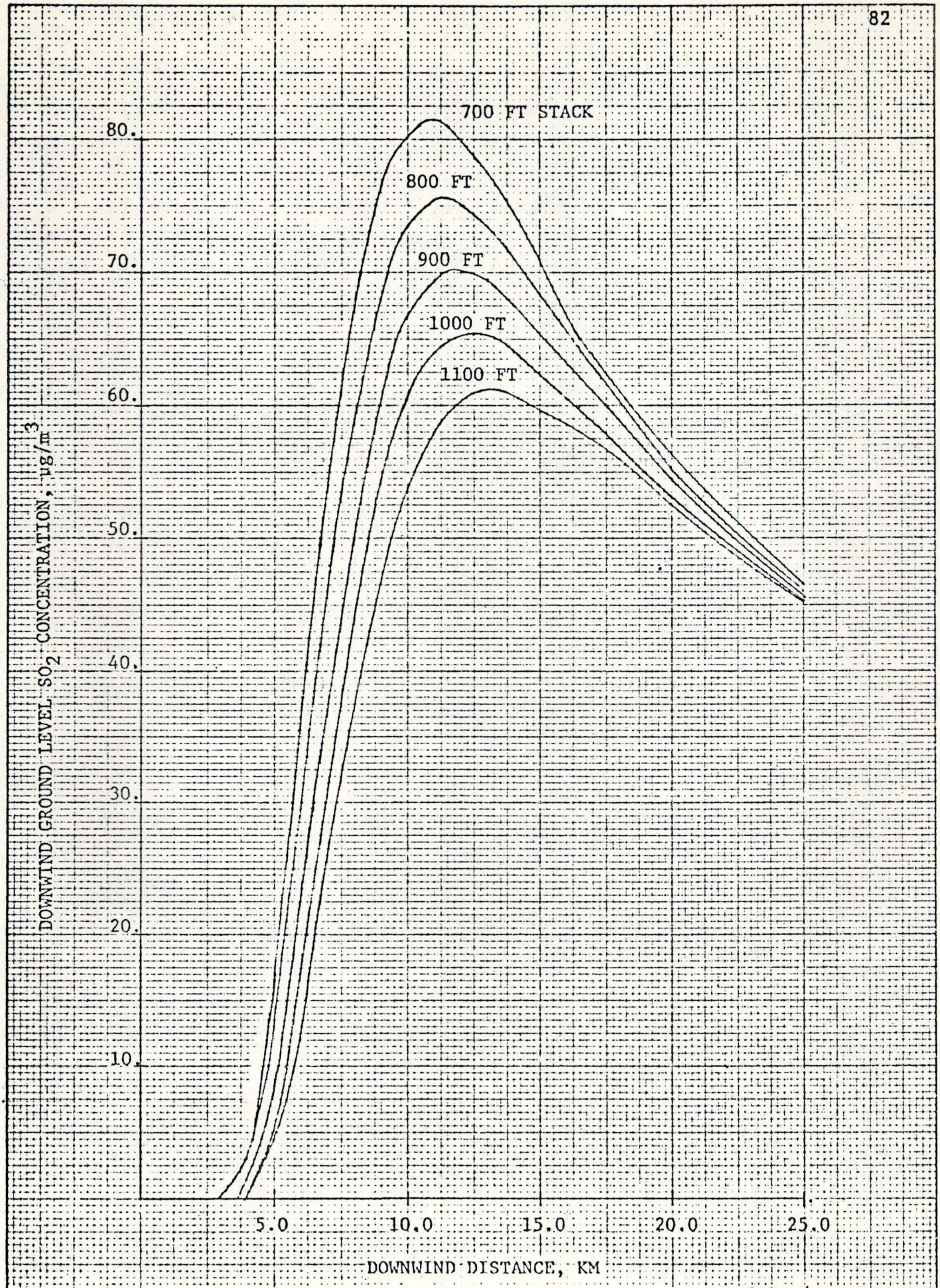

Figure 5-6. Downwind Ground Level SO_2 Concentration, 5.0 m/sec

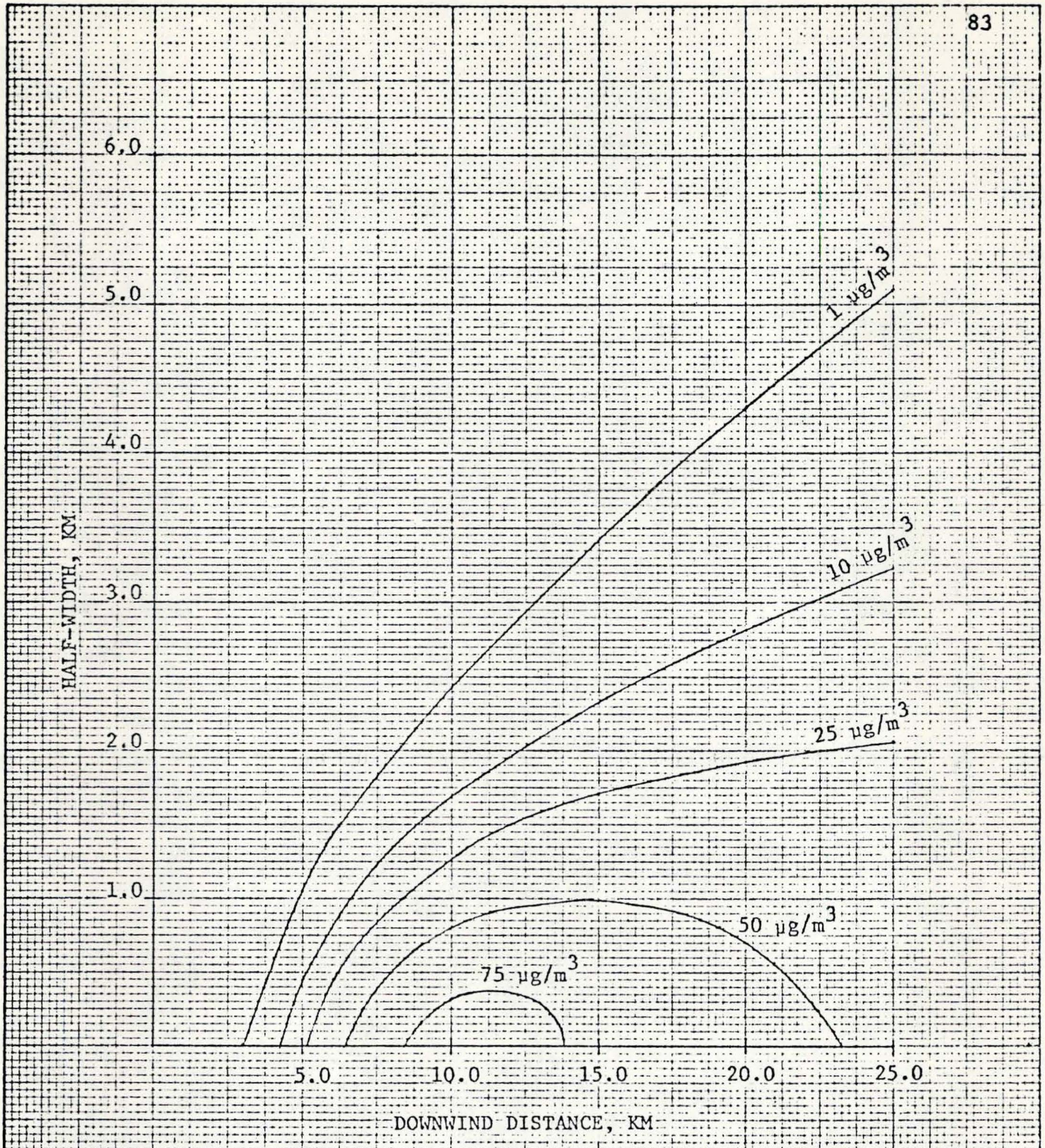

Figure 5-7. Isopleth Plot for SO_2 from 700 Foot Stack, 5.0 m/sec Wind Speed and Stability Class C

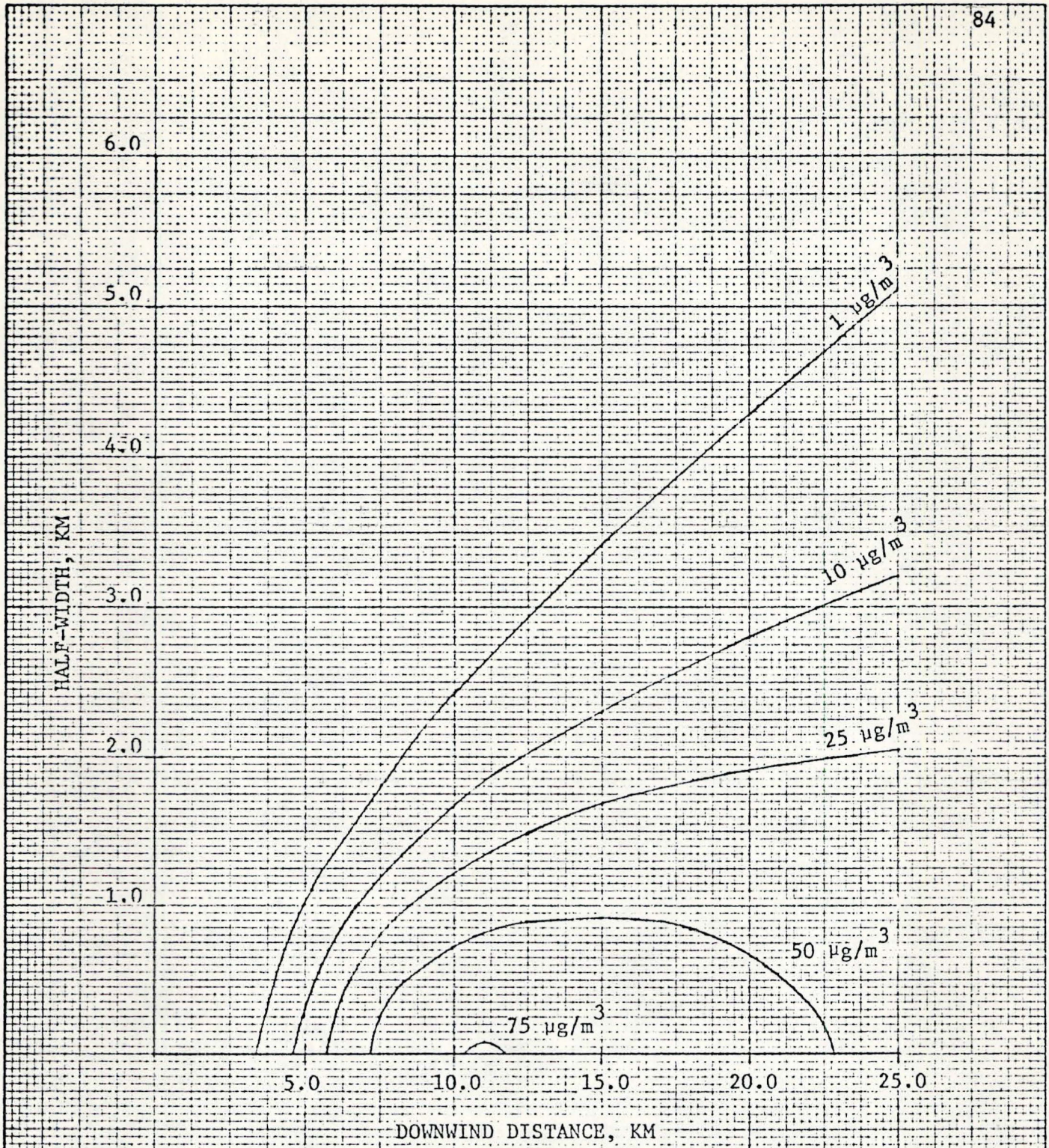

Figure 5-8. Isopleth Plot for SO_2 from 800 Foot Stack, 5.0 m/sec Wind Speed and Stability Class C

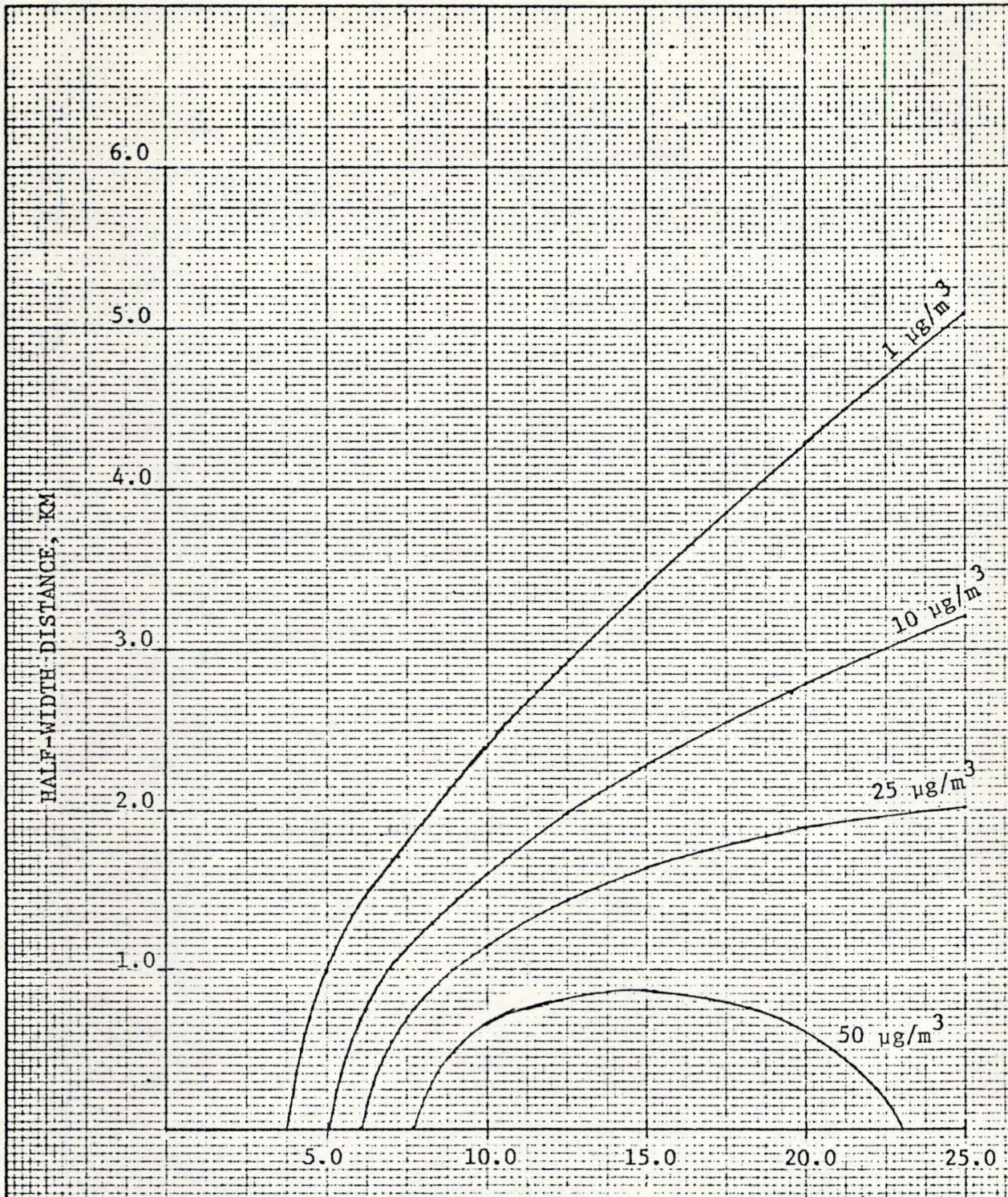

Figure 5-9. Isopleth Plot for SO_2 from 900 Foot Stack, 5.0 m/sec Wind Speed and Stability Class C

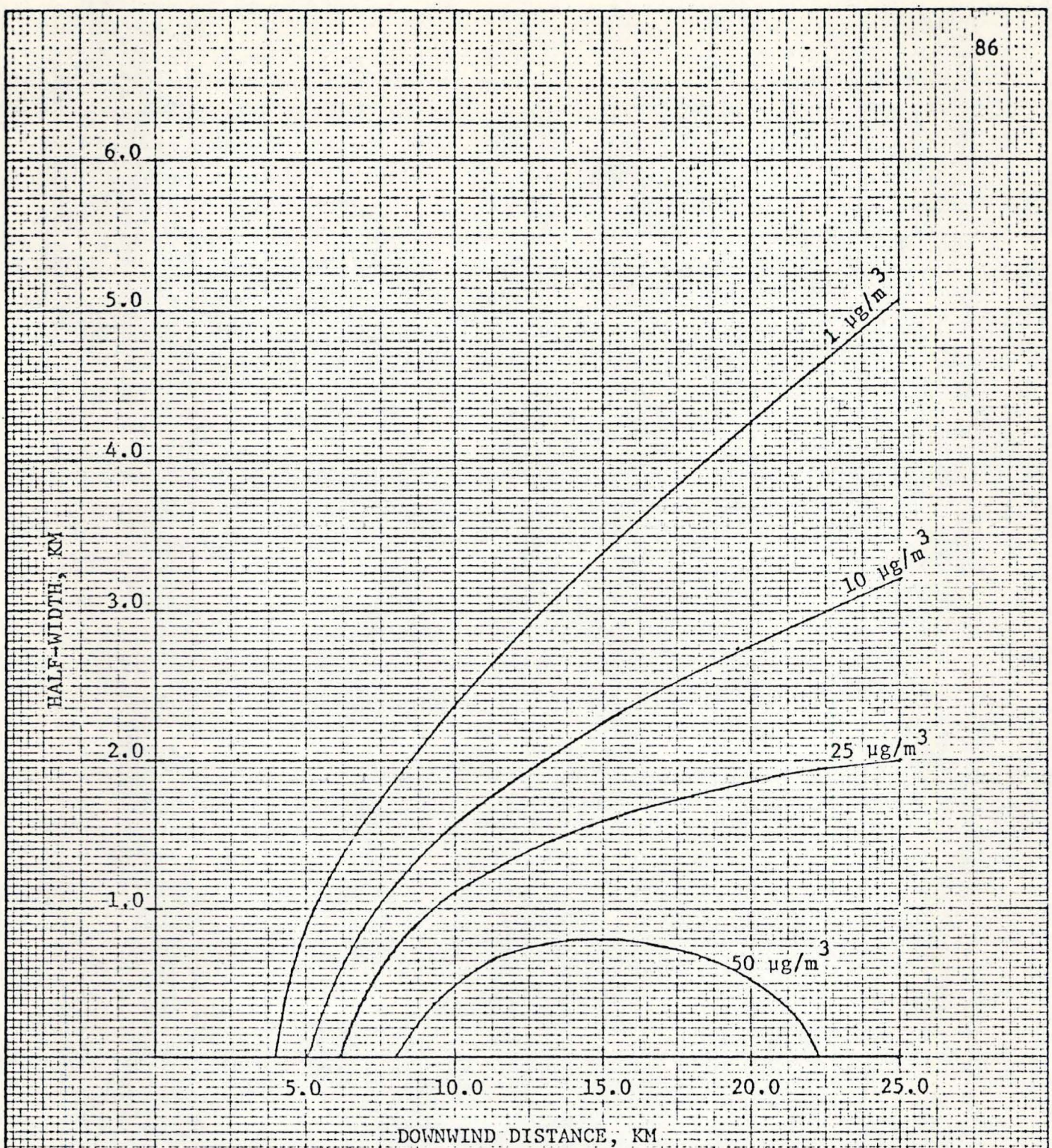

Figure 5-10. Isopleth Plot for SO_2 from 1000 Foot Stack, 5.0 m/sec Wind Speed and Stability Class C

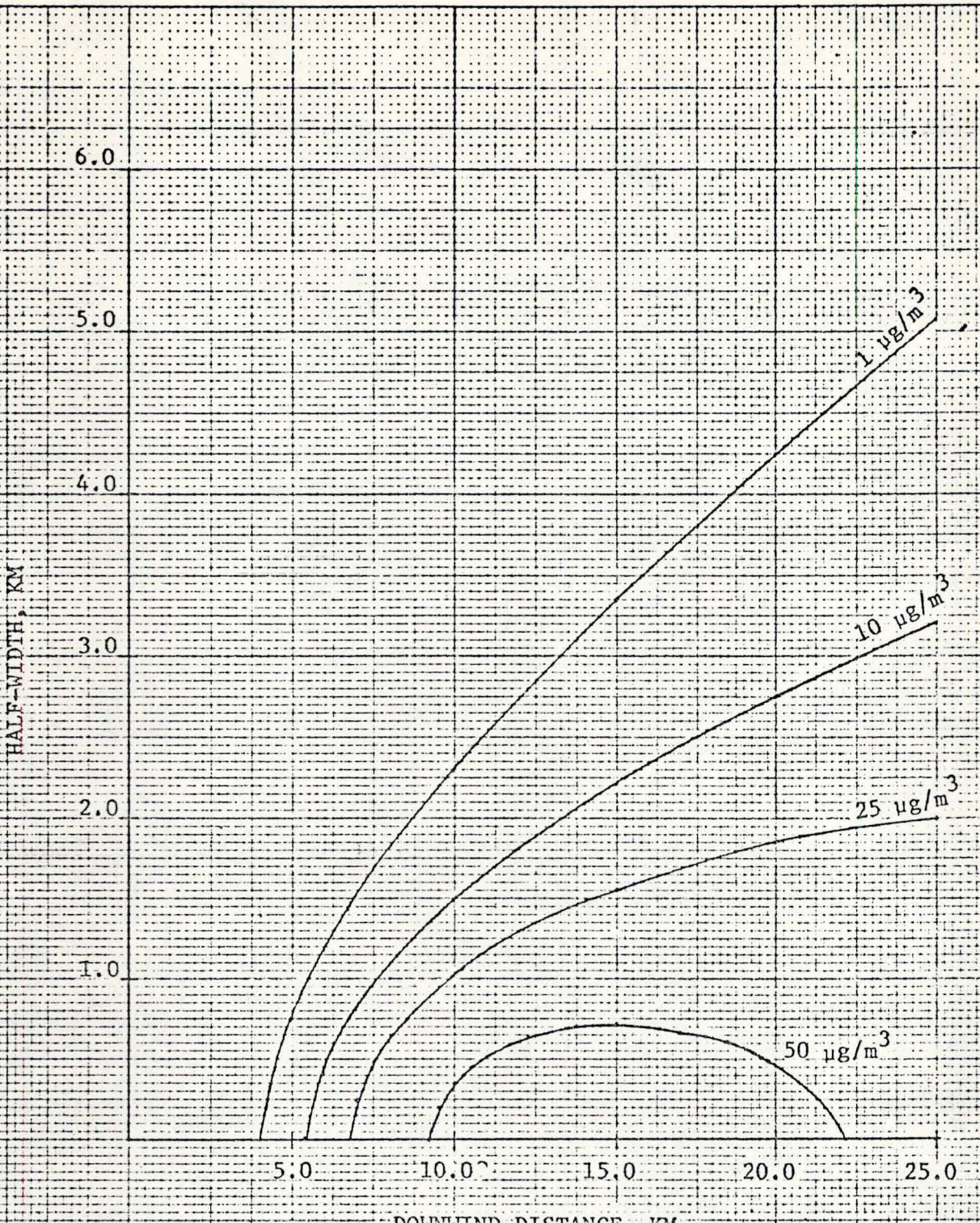

Figure 5-11. Isopleth Plot for SO_2 from 1100 Foot Stack, 5.0 m/sec Wind Speed and Stability Class C

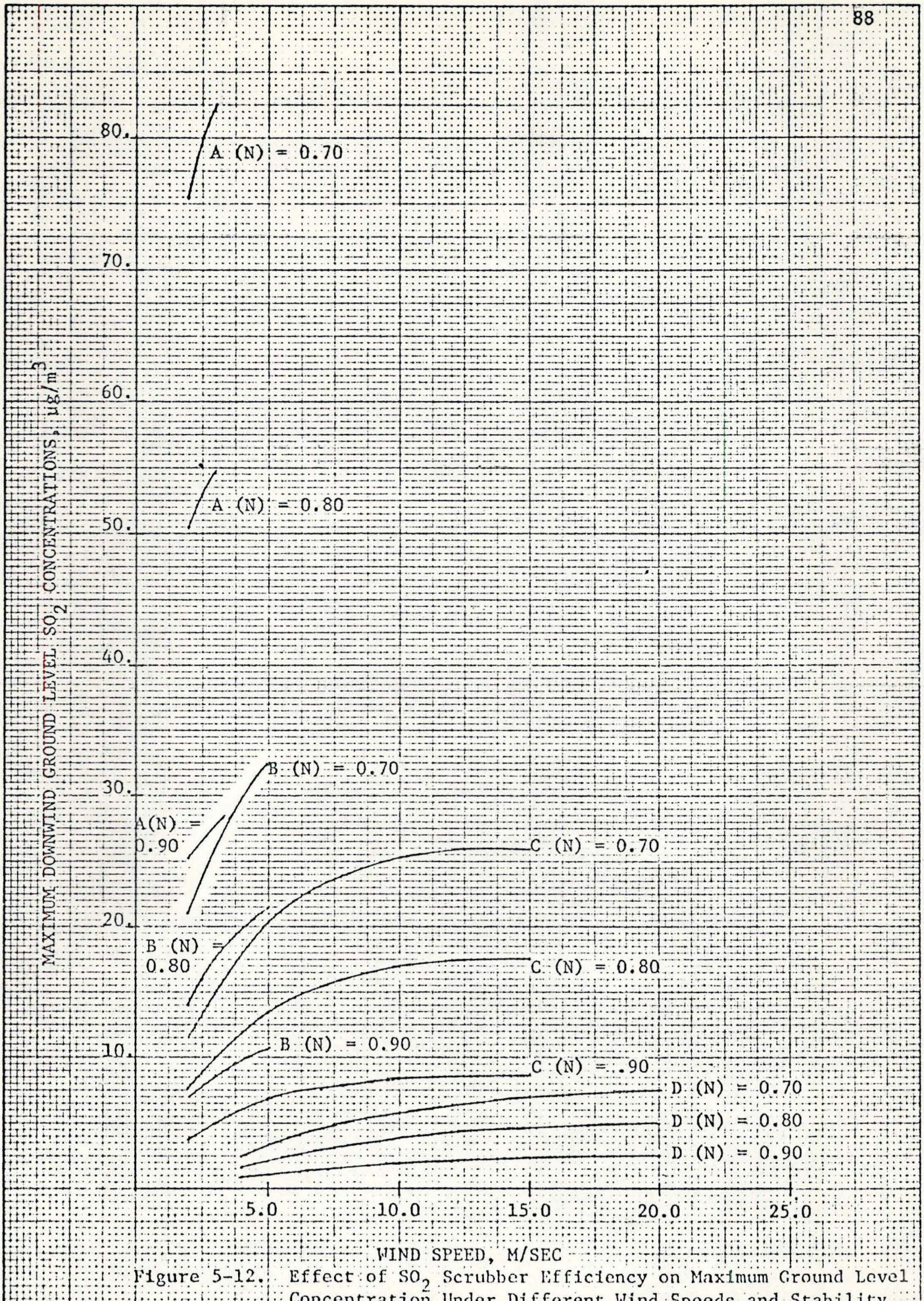

Figure 5-12. Effect of SO_2 Scrubber Efficiency on Maximum Ground Level Concentration Under Different Wind Speeds and Stability

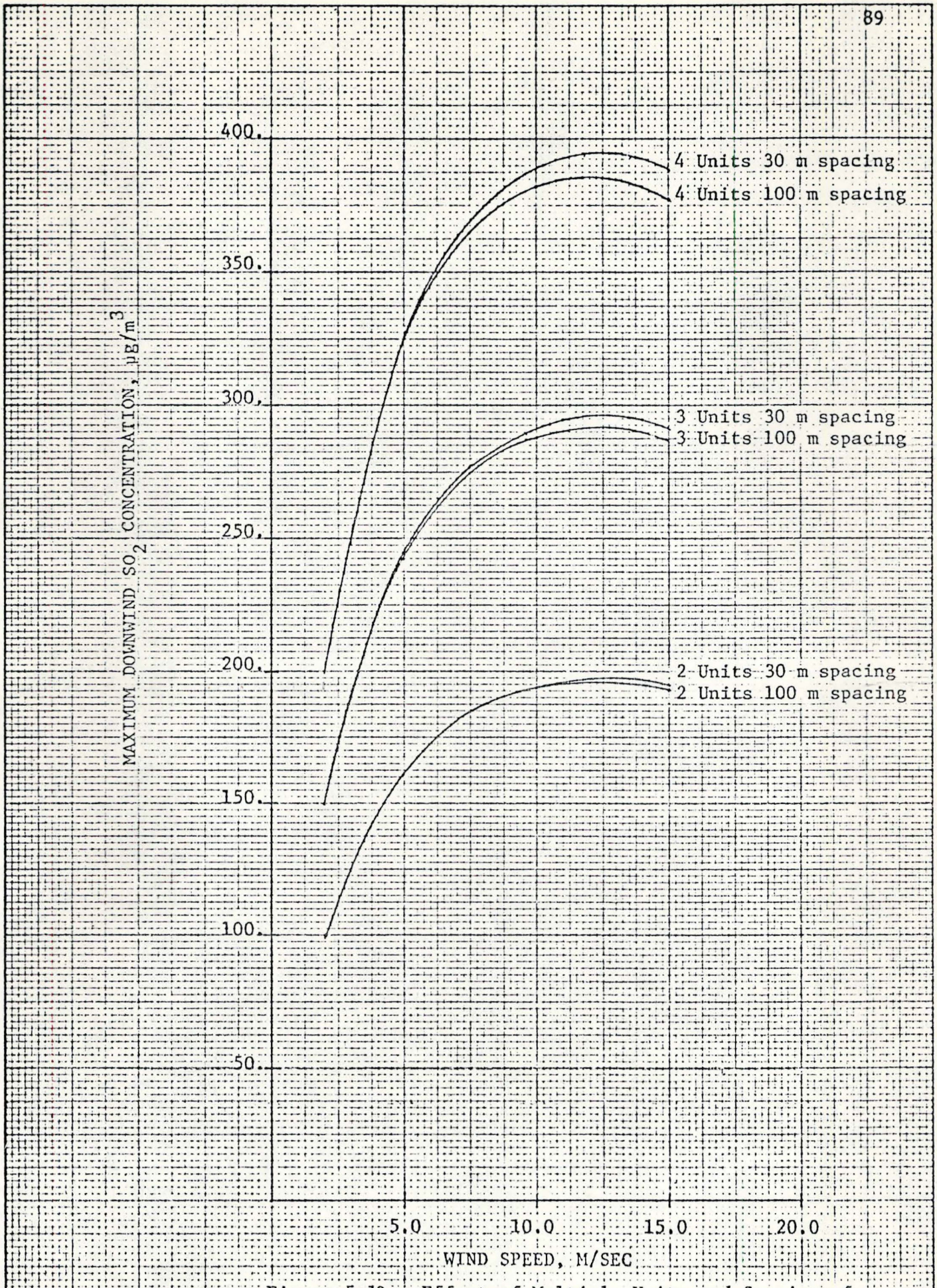

Figure 5-13. Effect of Multiple Units and Spacing of Stacks on Maximum Ground Level SO_2

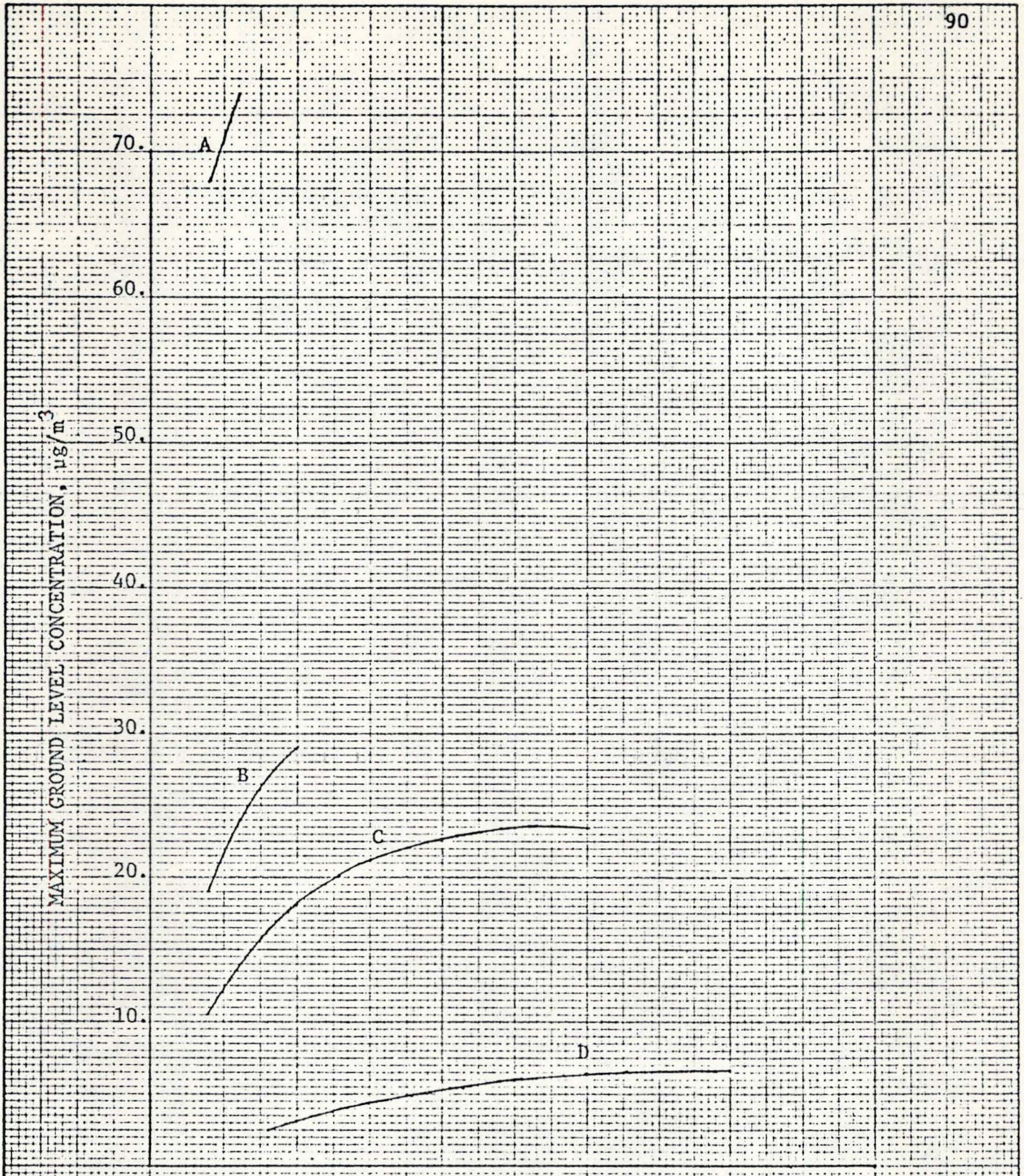

Figure 5-14. Maximum Ground Level NO_x Concentrations Under Different Wind Speeds and Stability Classes, 700 Foot Stack and Unlimited Mixing Height

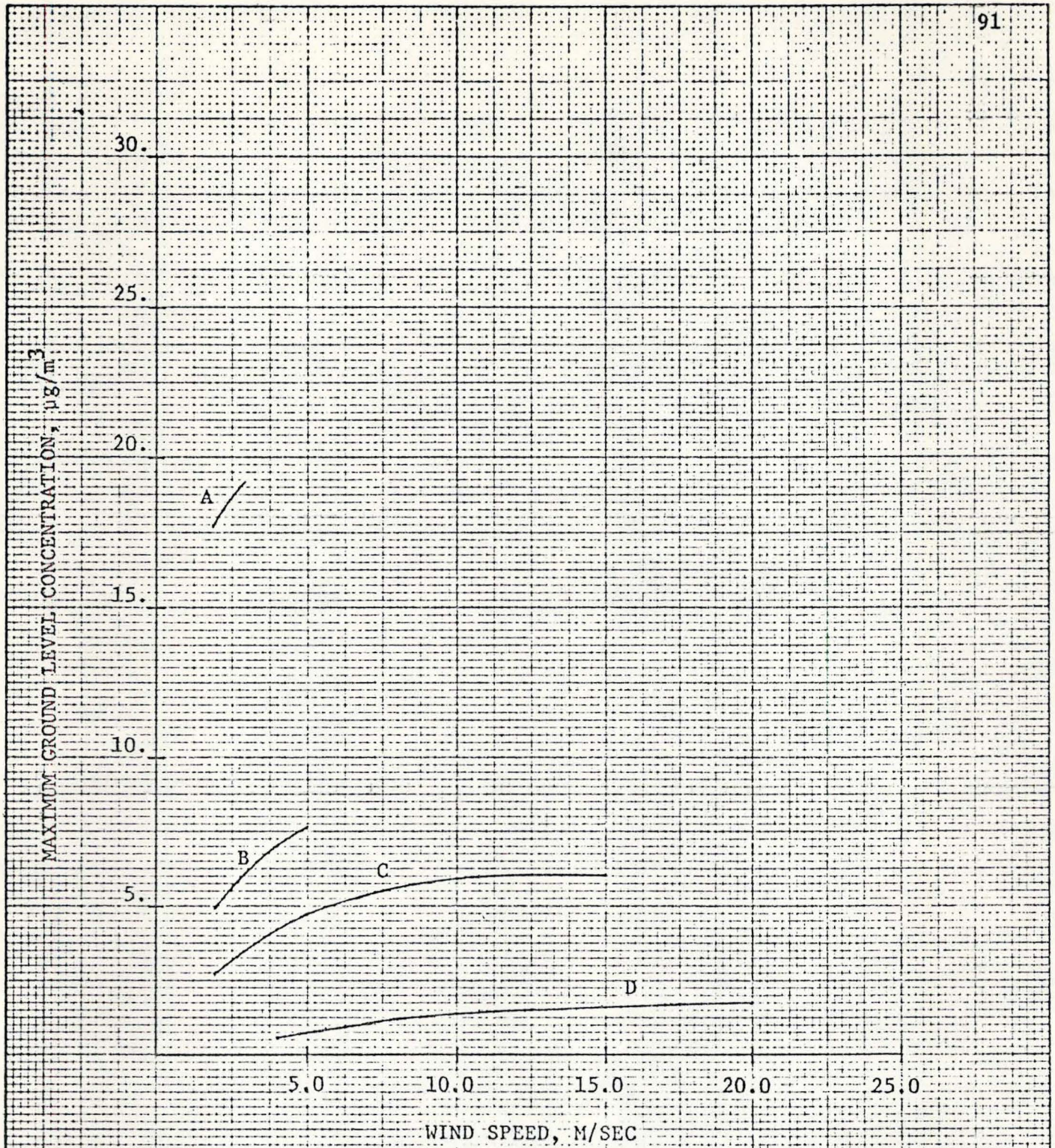

Figure 5-15. Maximum Ground Level Particulate Concentration Under Different Wind Speeds and Stability Classes, 700 Foot Stack and Unlimited Mixing Height

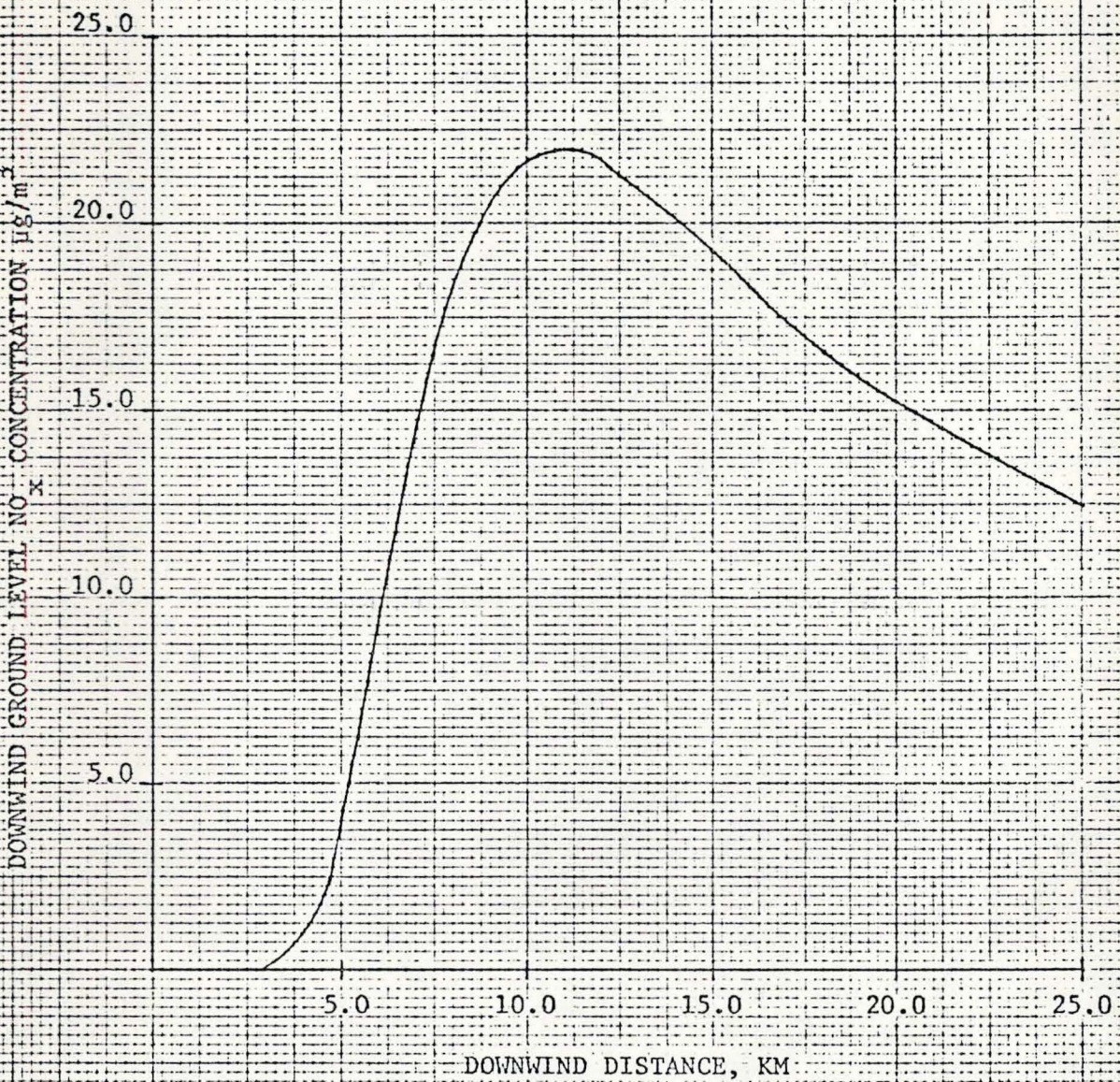

Figure 5-16. Downwind Ground Level NO_x Concentration for a 700 Foot Stack, Stability Class C and 5.0 m/sec Wind Speed

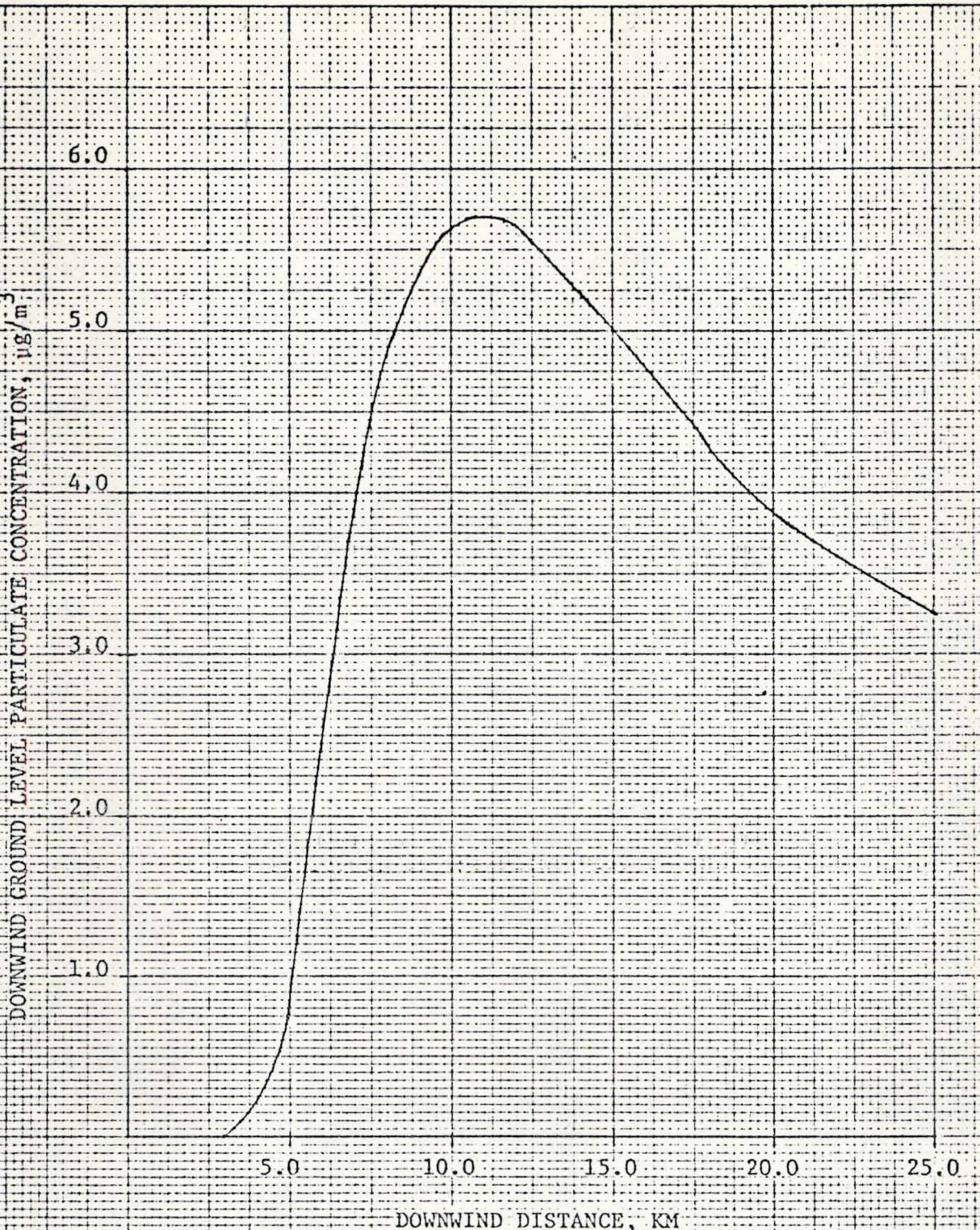

Figure 5-17. Downwind Ground Level Particulate Concentration from a 700 Foot Stack, Stability Class C and 5.0 m/sec Wind Speed

6. ESTIMATES OF AIR POLLUTION CONCENTRATIONS (GASIFICATION PLANTS)

The information presented in the previous chapters may also be used to estimate ground level concentrations of air pollutants from a coal gasification plant. The coal gasification plant to be studied is a general one, but in keeping with the theme of this thesis parameters common to North Dakota lignite coal and meteorology will be used.

The Federal and State air quality standards used in the study are the same as those given in Chapter 5. The meteorological discussion given in Chapter 5 is also applicable to this Chapter.

6.1 SO_2 Emission Rate Calculations

The plant to be studied was assumed to be capable of producing 250 million cubic feet of substitute natural gas per day. An assumption was made that all effluents of the plant will be emitted from a single stack. The physical parameters of the stack are given in Table 6-1.

The methods of Chapter 3 were used to estimate the amount of SO_2 to be emitted to the atmosphere from the gasifier units. The methods of Chapter 2 were used to estimate the amount of SO_2 to be emitted to the atmosphere from the auxiliary power plant and the steam generator. It was assumed that no scrubber would be used to remove sulfur dioxide from the stack effluents.

Table 6-1. Emission Data for SO_2 from a Coal Gasification Plant

Emission Rate (g/sec)	Stack Height (m)	Stack Gas Temp (^oK)	Volume Flow (m^3/sec)
1142.4	91.5	348.0	583.0

Converting to the units necessary for comparison to Federal and State standards, it was found that approximately 0.54 lbs of $SO_2/10^6$ BTU will be emitted from the plant. This emission rate does not exceed the Federal standards of 1.2 lbs/10^6 BTU or the State standards of 3.0 lbs/10^6 BTU.

6.2 SO_2 Ground Level Concentrations

For the coal gasification plant the meteorological parameters that will be investigated that affect ground level concentration are stability class, windspeed, and mixing layer height. Variation of stack height is not expected to be used to reduce ground level concentrations of air pollutants from a coal gasification plant; therefore, the effect of stack height on ground level concentrations was not investigated.

Stability Class and Windspeed

To study the effect of various atmospheric stabilities and windspeeds on the maximum ground level concentration of SO_2 the data of Table 6-1 was input to the PTMAX computer program. The results are plotted in Figure 6-1. The results indicate that under a stability class A and low windspeeds the maximum short term concentrations (10 minute averaging time) occur. The maximum calculated ground level concentration is 750 $\mu g/m^3$. Using the methods described in Chapter 5 to convert from the valid averaging times of the computer estimations to the averaging times for State and Federal standards, the estimated maximum ground level concentrations of SO_2 will not exceed Federal or State standards.

In addition to calculating the maximum ground level concentration, PTMAX calculates the downwind distance to the maximum concentration and the effective height of the plume at the point of maximum concentration.

The distance to the maximum ground level SO_2 concentration and the effective height of the plume are plotted on Figures 6-2 and 6-3, respectively.

Mixing Layer Height

The atmospheric mixing height may have considerable effect on the maximum ground level concentrations of air pollutants. To study this effect on SO_2 emitted from a coal gasification plant a series of computer runs were made using the PTDIS program. The results are plotted on Figure 6-4. The results indicate that the mixing height has little effect on the maximum concentration at windspeeds greater than 5.0 m/sec. Below 5.0 m/sec the effect is large if the mixing height is below 750 meters. The results indicate that at a mixing height of 400 meters and a windspeed of 2.0 m/sec the maximum ground level concentration of SO_2 would exceed the North Dakota State standard of 715 $\mu g/m^3$ for a one hour averaging period. The results indicate that under these conditions a scrubber would be required to remove some of the SO_2 from the effluents of the stack. The scrubber efficiency would need to be at least 0.30 to reduce the ground level concentrations to an acceptable level.

Downwind SO_2 Concentrations

The PTDIS program was used to estimate the ground level concentration at various downwind distances at a class C stability, a windspeed of 5.0 m/sec, and a mixing height of 1500 meters. The results are plotted on Figure 6-5. Figure 6-6 contains an isopleth plot from the same PTDIS run. The parameters input to the program are found in Table 6-1.

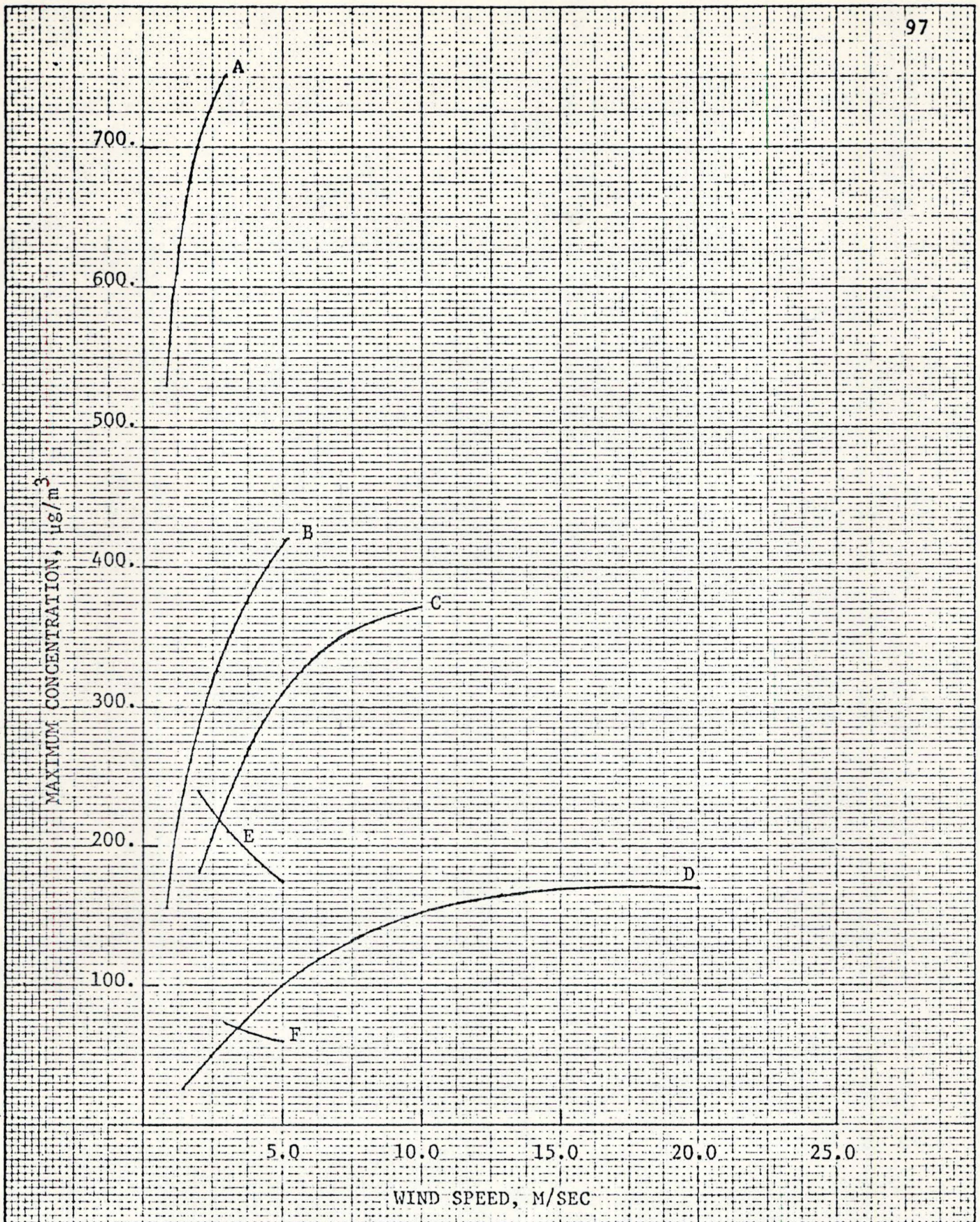

Figure 6-1. Maximum SO_2 Concentration During Unlimited Mixing Conditions Under Different Wind Speeds and Stability Classes.

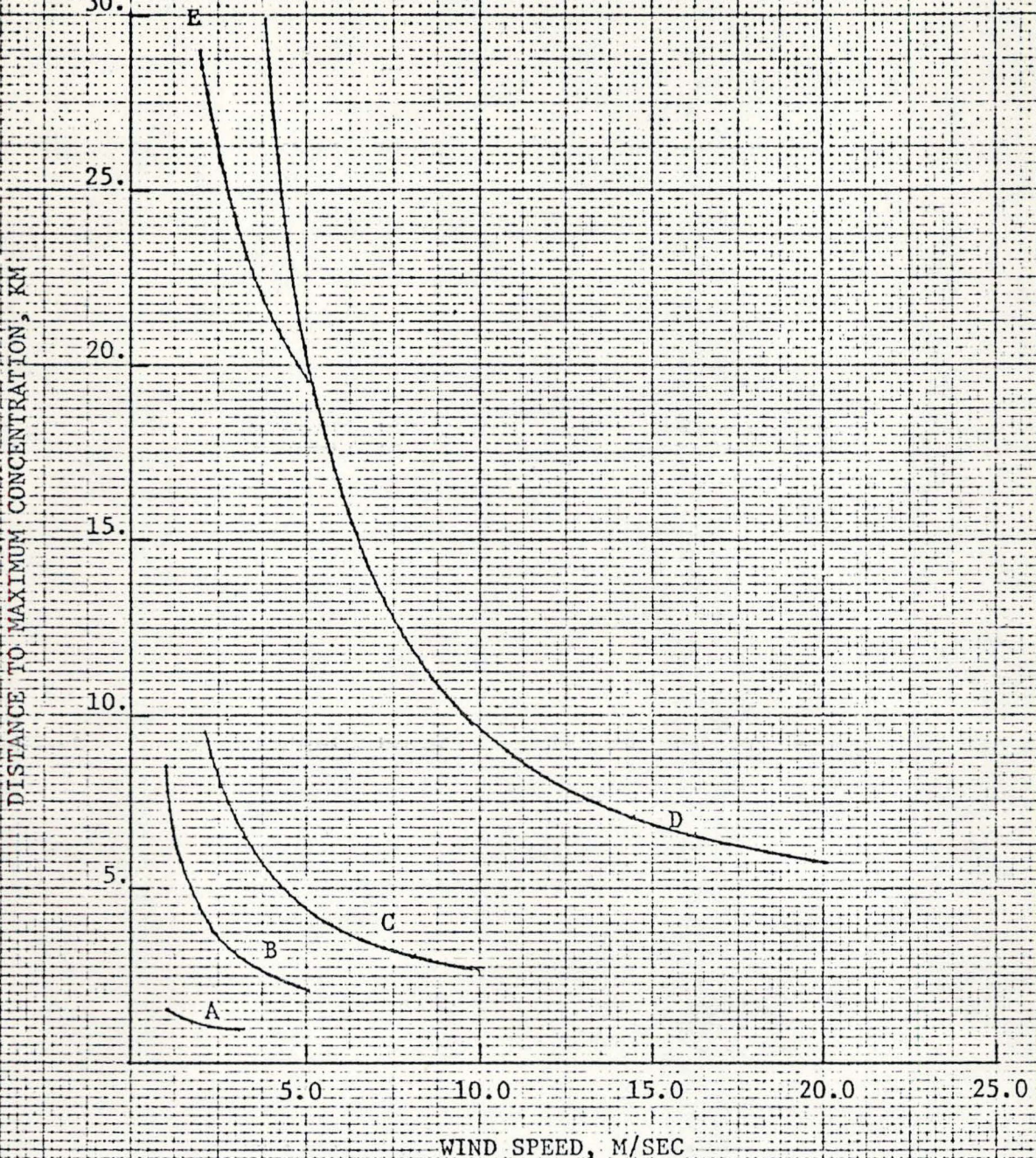

Figure 6-2. Distances to Maximum SO_2 Concentrations Under Different Wind Speeds and Stability Classes

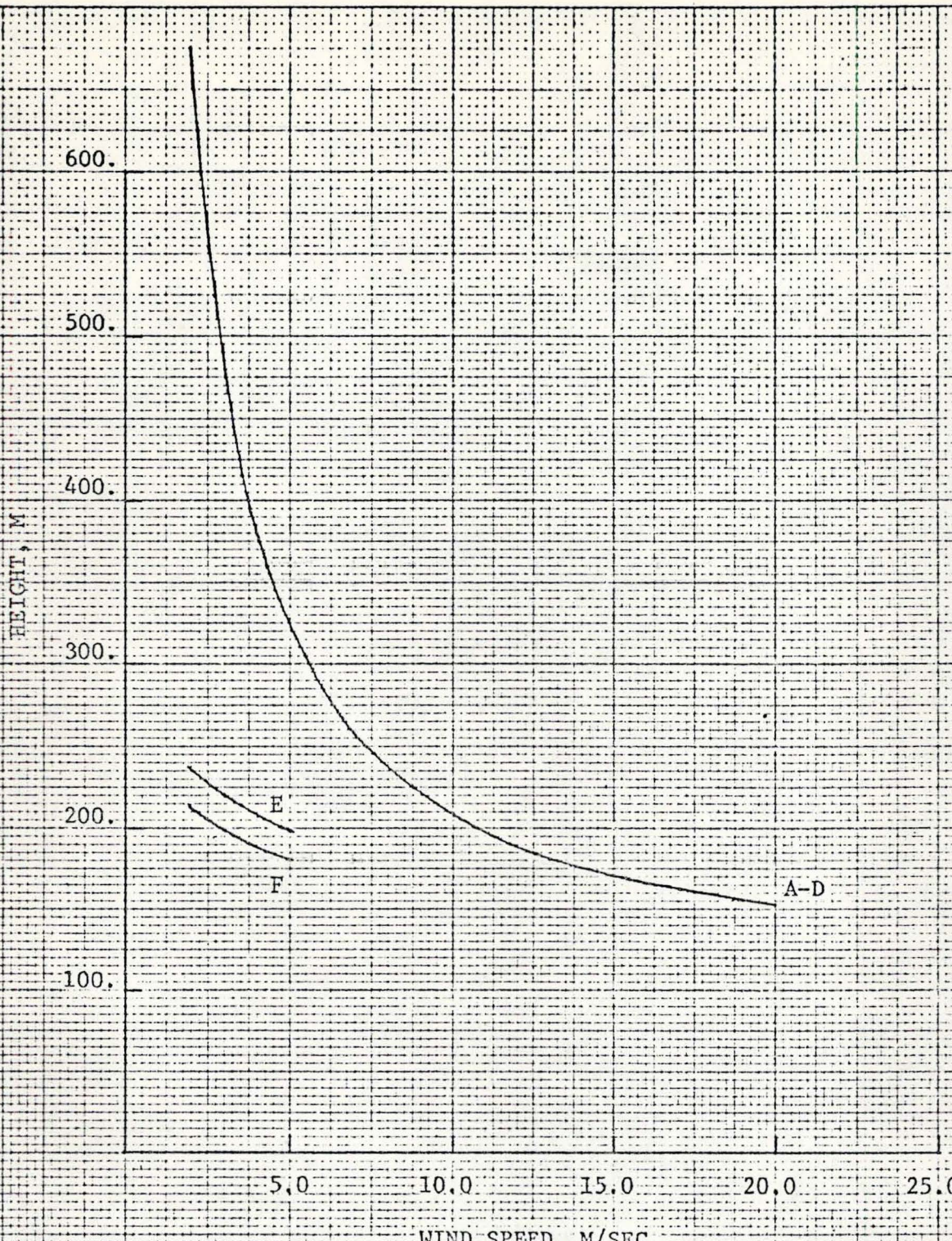

Figure 6-3. Stack Effective Height Under Different Wind Speeds and Stability Classes

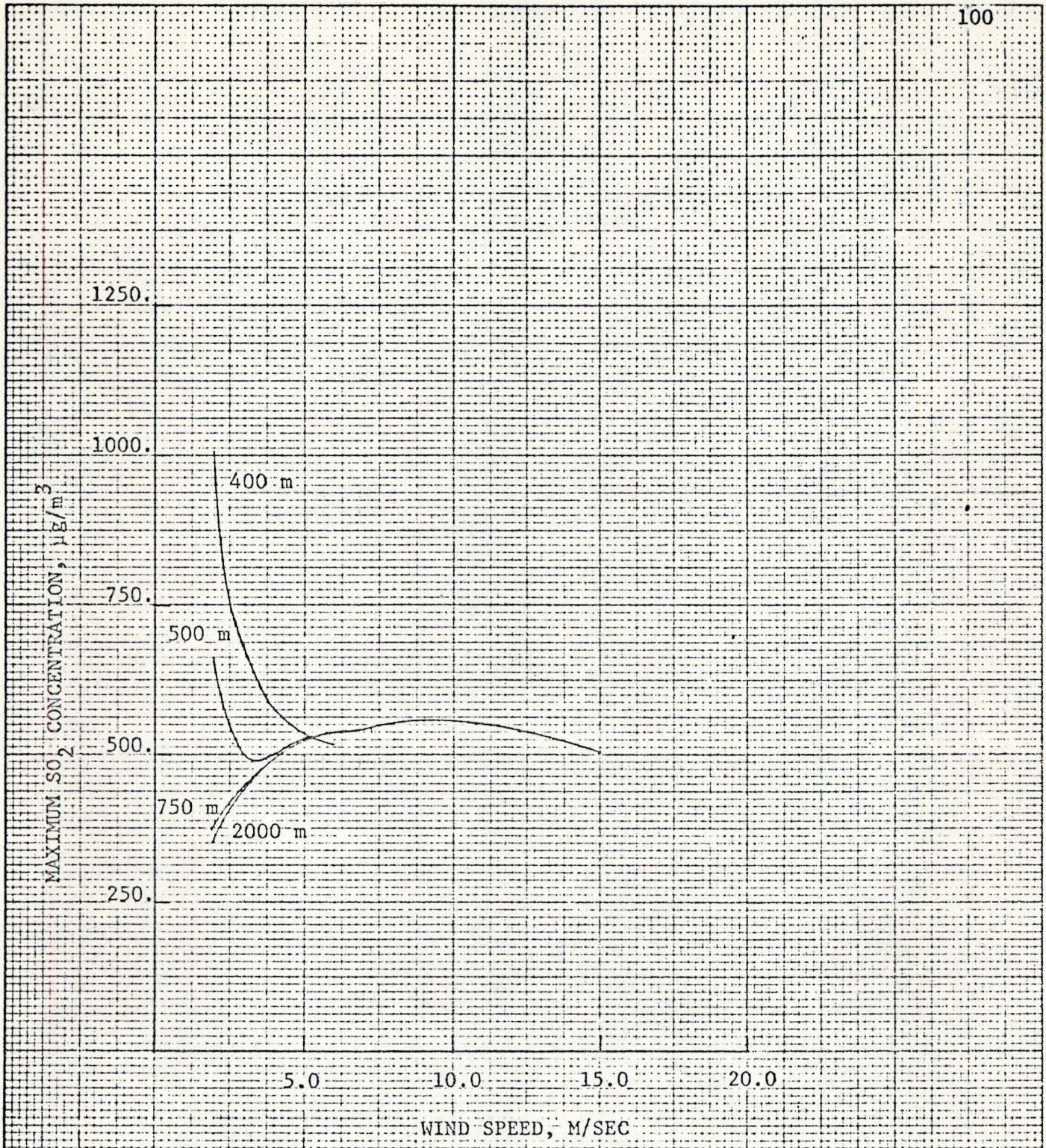

Figure 6-4. Effect of Mixing Height on Maximum Ground Level SO_2 Concentrations, Stability Class C

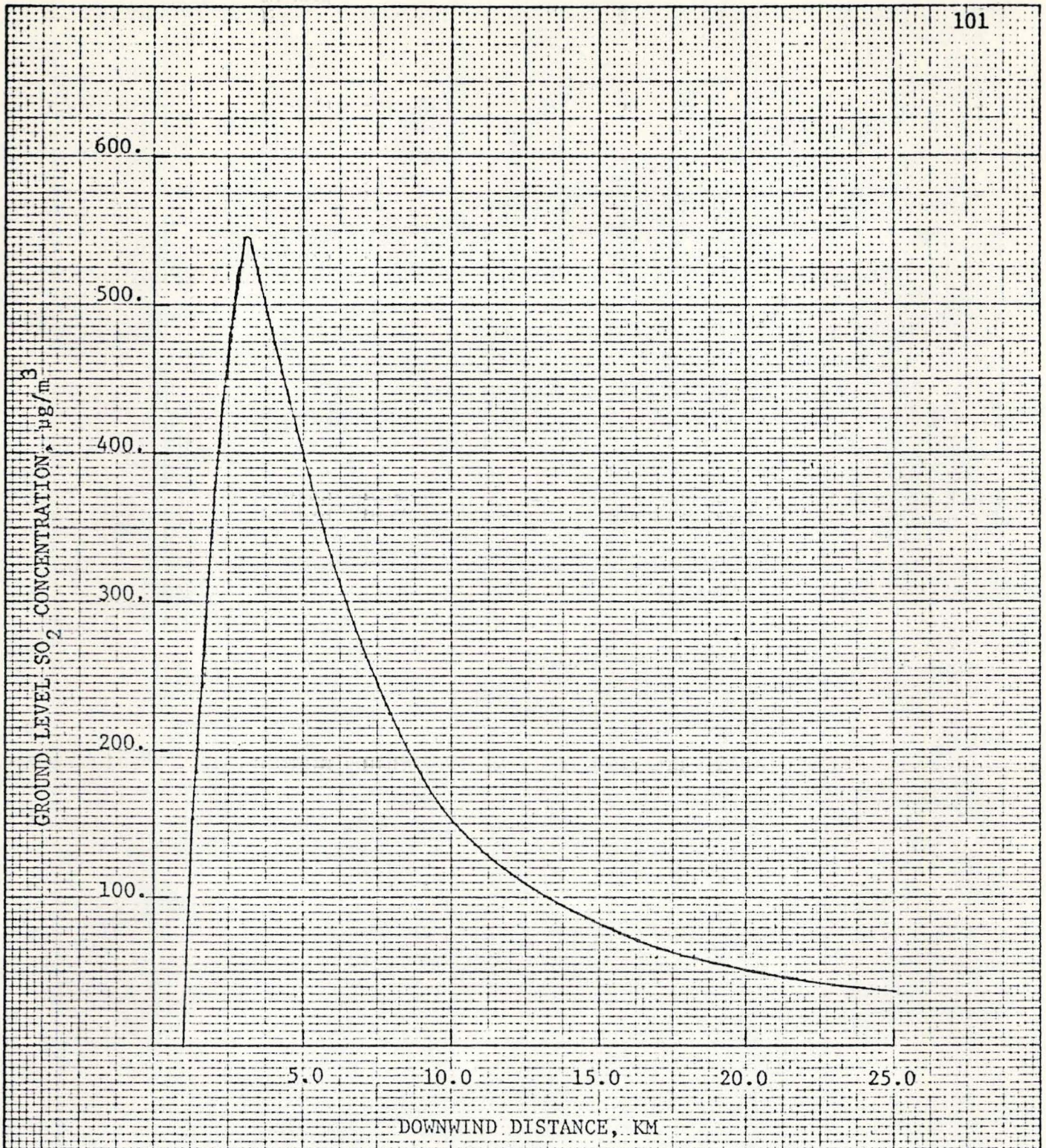

Figure 6-5. Downwind Ground Level SO_2 Concentrations, Stability Class C, Wind Speed = 5.0 m/sec

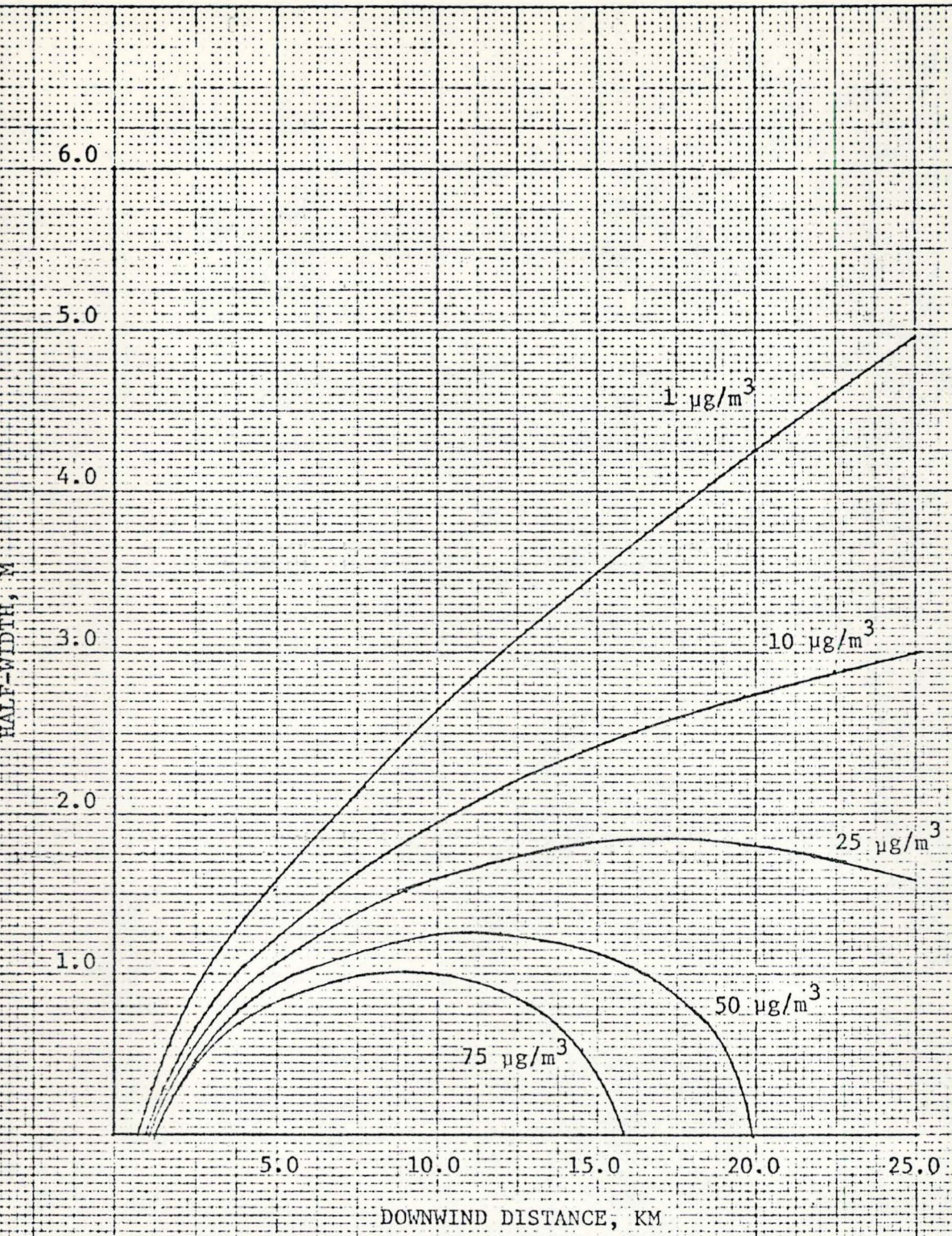

Figure 6-6. SO_2 Isopleth Plot, Stability Class C
Wind Speed = 5.0 m/sec

7. CONCLUDING REMARKS

The methods described in this thesis for estimating the products and byproducts from coal fired electrical generating plants and coal gasification plants give results that are reasonable for first estimates. If exact results are required a more detailed analysis will have to be made.

The computer programs described are generally not difficult to use. The necessary input and resulting output is not difficult to understand or interpret. The use of these programs does require a basic understanding of atmospheric conditions and parameters, such as stability classes, and the program requires a knowledge of the mathematical models used to make the air pollution concentration estimates.

The investigation of the possible impact on the air quality in western North Dakota by the hypothetical plants indicate that air pollution control equipment will be necessary to avoid exceeding State and Federal Air Pollution Regulations. Generally, the facilities will not exceed the stated regulations, but under certain atmospheric conditions temporary rises in air pollution concentration levels can be expected. When these conditions exist, primarily low mixing heights, the plant operation will either have to be curtailed or air pollution control equipment will have to be used.

A comparison of the estimated SO_2 concentrations from a coal fired electrical generating plant and coal gasification plant can be made assuming no SO_2 scrubbers are used. Although a 600 mw electrical generating plant may emit 50% more SO_2 to the atmosphere than a 250 MMSCFD coal gasification plant, the coal gasification plant will generally

create higher ground level concentrations of SO_2 because of its shorter stack.

The study of these two facilities does indicate that they will have a considerable impact on the air quality in western North Dakota, but with the use of air pollution control equipment the impact can be minimized and reduced to acceptable levels. An area that was not studied is the effect of placing several electrical generating and coal gasification units throughout western North Dakota. The building of a large number of these units in the western part of the state may have an unacceptable cumulative effect on the air quality and the problem will have to be studied further in the future.

Generally, coal fired electrical generating plants emit more contaminates per ton of coal consumed than do coal gasification plants. Therefore, it has been suggested that a combined cycle plant be used to produce electrical energy. This plant would gasify the coal and then the gas produced could be used to either drive a gas turbine or be used in a steam generator to produce electrical energy. The study of the impact on the air quality from such a plant was beyond the scope of this thesis, but it is a problem that should be studied in the future.

15. Perkins, Henry C., Air Pollution

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Appendix A
1. Deck Set-Up for PTDIS

Job Card - Self Explanatory

JCL Cards

JCL Card 1a

```
// EXEC FORTRAN
```

JCL Card 1b*

```
// EXEC FORTRAN,PAM.FORT='NOSOURCE,NOMAP'
```

JCL Card 2

```
//FORT.SYSIN DD UNIT=2400,
```

JCL Card 3

```
// LABEL=(5,SL,,IN),DSN=PROGRAM,
```

JCL Card 4

```
// VOL=SER=NDST16,
```

JCL Card 5

```
// DISP=OLD
```

JCL Card 6

```
//GO.SYSIN DD *
```

* Replace JCL card 1a with 1b to eliminate a source listing for each run.

Appendix A (Continued)
1. PTDIS Deck Set-Up

Data Cards

Data Card Type 1 (Title Card) One Card - Any Alphanumeric Character

TEST CASE FOR PTDIS

Data Card Type 2 (Control Card) One Card

I10	I10	I10	I10	F10.0	
N	I	J	IN	S	
10	20	30	40	50	

N = number of distances (up to 50).
I = control for isopleths.
I = 1: no isopleths; I = 2: consider isopleths
J = control for calculation of effective height.
J = 1: calculate effective height; J = 2: specify effective height
IN = number of isopleths if any (up to 8).
S = wind segment size (degrees).

Data Card Type 3, (Distance Card) One to Seven Cards

F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	F10.0
XN	XN	XN	XN	XN	XN	XN	XN
10	20	30	40	50	60	70	80

XN = downwind distance (kilometers).

Data Card Type 4 (Isopleth Card) One Card, Read Only if I = 2

E10.5	E10.5	E10.5	E10.5	E10.5	E10.5	E10.5	E10.5
PL	PL	PL	PL	PL	PL	PL	PL
10	20	30	40	50	60	70	80

PL = isopleth values (grams/meter^3).

Data Card Type 5a (Source Card) One Card, Used if J = 1

F10.0	F10.0	F10.5	F10.5	F10.5	F10.5	
Q	HP	TS	VS	D	VF	

Q = source strength (grams/sec).
HP = physical height of the stack (meters).
TS = stack gas temperature (degrees kelvin).
VS = stack gas velocity (meters/sec).
D = diameter of the stack (meters).
VF = volume flow (meters^3/sec). VF may be left blank. D and VS will be used to calculate VF. If VF is given it is assumed correct and D and VS are not used.

Data Card Type 5b (Source Card) One Card, Used if J = 2

F10.0	F10.0	
Q	H	
10	20	

Q = source strength (grams/sec).
H = effective height of emission (meters).

1. PTDIS Deck Set-Up

Data Card Type 6 (Meteorology Card) Any Number of Cards, The Last One Blank for Control

10X	F10.0	I1	9X	F10.0	F10.0	
	U	KST		HL	T	
1	10	20 21	30	40	50	

U = wind speed (meters).
KST = stability class (dimensionless).
HL = mixing height (meters).
T = ambient air surface temperature (degrees kelvin). T can be left blank and a value of T = 293° K will be used.

Data Card Type 7 (Control Card) One Card, Control for Program Flow

I1
KNTRL
1

KNTRL = 0 is used to call exit.
KNTRL = 1 is used to return to redefine controls.
KNTRL = 2 is used to go back and read new source information.

Last Card in the Deck (Blue Card)

// JOB END*

Appendix A
2. Deck Set-Up for PTMAX

Job Card - Self Explanatory

JCL Card 1a

```
// EXEC FORTRAN
```

JCL Card 1b*

```
// EXEC FORTRAN,PARM.FORT='NOSOURCE,NOMAP'
```

JCL Card 2

```
//FORT.SYSIN DD UNIT=2400,
```

JCL Card 3

```
// LABEL=(6,SL,,IN),DSN=PROGRAM,
```

JCL Card 4

```
// VOL=SER=NDST16,
```

JCL Card 5

```
// DISP-OLD
```

JCL Card 6

```
//GO.SYSIN DD *
```

* JCL card 1a may be replaced by 1b if no source listing of the program is required.

Data Card Type 1 (Title Card) One Card - Any Alphanumeric Character

TEST CASE FOR PTMAX

Data Card Type 2 (Source Card) One Card

F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	
Q	HP	TS	VS	D	VF	
10	20	30	40	50	60	

Q = source strength (grams/sec).
HP = physical stack height (meters).
TS = stack gas temperature (degrees kelvin).
VS = stack gas velocity (meters/sec).
D = stack diameter (meters).
VF = volume flow ($meters^3$/sec). VF may be left blank and VS and D will be used to calculate VF. If VF is given it is assumed correct and VS and D are not used.

Any number of sets consisting of one title card and one source card may be used. The last set must be followed by two blank cards.

Blue Card - Last Card of the Program Deck

//	JOB END*

Appendix A
3. Deck Set-Up for PTMTP

Job Card - Self Explanatory

JCL Cards

JCL Card 1a

```
// EXEC FORTRAN
```

JCL Card 1b*

```
// EXEC FORTRAN,PARM.FORT='NOSOURCE,NOMAP'
```

JCL Card 2

```
//FORT.SYSIN DD UNIT=2400,
```

JCL Card 3

```
// LABEL=(7,SL,,IN),DSN=PROGRAM,
```

JCL Card 4

```
// VOL=SER=NDST16,
```

JCL Card 5

```
//DISP=OLD
```

JCL Card 6

```
//GO.SYSIN DD *
```

* Replace card 1a with 1b if no source listing of the program is required.

Appendix A (Continued)
3. PTMTP Deck Set-Up

Data Cards

Data Card Type 1 (Title Card) One Card - Any Alphanumeric Character

TEST CASE FOR PTMTP

Data Card Type 2 (Control Card) One Card
I10

X	
10	

X = 1: prints partial concentrations.
X = 2: does not print partial concentrations.

Data Card Type 3 (Source Card) Up to 26 Cards

F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	F10.0	F10.0
Q	HP	TS	VS	D	VF	RQ	RS
10	20	30	40	50	60	70	80

Q = source strength (grams/sec).
HP = physical stack height (meters).
TS = stack gas temperature (degrees kelvin).
VS = stack gas velocity (meters/sec).
D = stack diameter (meters).
VF = volume flow (meters^3/sec). VF can be left blank and VS and D will be used to calculate a volume flow. If VF is given it is assumed correct and VS and D are not used.
RQ = R coordinate (kilometers). R is the abscissa of the cartesian coordinate system.
RS = S coordinate (kilometers). S is the ordinate of the cartesian coordinate system.

A single blank card must follow the last source card for control.

Data Cards

Data Card Type 4 (Receptor Card) Up to 31 Cards

F10.0	F10.0	F10.0	
RREC	SREC	Z	
10	20	30	

RREC = R coordinate (kilometers). R coordinate is the abscissa of the cartesian coordinate system.
SREC = S coordinate (kilometers). S coordinate is the ordinate of the cartesian coordinate system.
Z = height of the receptor above the ground (meters).

A single blank card must follow the last receptor card for control

Data Card Type 5 (Meteorology Card) Any Number of Cards

F10.0	F10.0	I1	9X	F10.0	F10.0	F10.0	
THETA	U	KST		HL	T	P	
10		2021	30	40	50	60	

THETA = wind direction (degrees).
U = wind speed (meters/sec).
KST = stability class (dimensionless). The numbers 1-6 correspond to Pasquill's stabilities A-F, respectively.
HL = mixing height (meters).
T = ambient air surface termperature (degrees kelvin).
P = ambient air pressure (millibars). T and/or P may be left blank, and default values of T=293°K and P=960mb will be used.

A single blank card must follow the last meteorology card for control.

The Last Card In The Program Deck (Blue Card)

//	JOB END*

APPENDIX B

1. PTDIS

```
D8T43 VERSION 74333
          EFFECT OF MIXING HEIGHT ON GROUND LEVEL CONCENTRATION

CONCENTRATION ESTIMATES. D8T43.

CARE SHOULD BE EXERCISED IN THE INTERPRETATION OF THESE CALCULATED CONCENTRATIONS. CONCENTRATION ESTIMATES MAY BE
   EXPECTED TO BE WITHIN A FACTOR OF THREE FOR 1) ALL STABILITIES FOR DISTANCES OF TRAVEL OUT TO A FEW HUNDRED METERS,
   2) NEUTRAL TO MODERATELY UNSTABLE CONDITIONS FOR DISTANCES OUT TO A FEW KILOMETERS, AND 3) UNSTABLE CONDITIONS IN
   THE LOWER 1000 METERS OF THE ATMOSPHERE WITH A MARKED INVERSION ABOVE FOR DISTANCES OUT TO 10 KILOMETERS OR MORE.
   FOR OTHER CONDITIONS THE ESTIMATES BECOME LESS RELIABLE FOR EXTREMES OF STABILITY AND AS TRAVEL DISTANCE INCREASES.

WIND SPEED =  2.0 M/SEC, STABILITY CLASS =  3,HEIGHT OF MIXING =  400. METERS, AMBIENT TEMPERATURE = 319.7 DEG K.

EMISSION RATE (G/SEC) = 1605.00, EFFECTIVE HEIGHT (M) =  395.0

DISTANCE  EFFECTIVE  CONCENTRATION  SIGY      SIGZ      CHI * U / Q   MDUM  ANDUM
  KM      HEIGHT(M)     G/M**3        M.        M.        SEC/M**3
```

DISTANCE KM	EFFECTIVE HEIGHT(M)	CONCENTRATION G/M**3	SIGY M.	SIGZ M.	CHI * U / Q SEC/M**3	MDUM	ANDUM
1.000	395.0	4.70E-11	103.11	61.14	5.86E-14	4	1.
2.000	395.0	5.61E-05	193.45	115.26	6.99E-08	4	1.
3.000	395.0	6.24E-04	279.00	167.01	7.78E-07	4	2.
4.000	395.0	1.20E-03	361.47	217.27	1.49E-06	4	2.
5.000	395.0	1.41E-03	441.64	266.47	1.75E-06	4	2.
6.000	395.0	1.39E-03	519.98	314.82	1.74E-06	4	2.
7.000	395.0	1.29E-03	596.81	362.49	1.61E-06	4	2.
8.000	395.0	1.18E-03	672.34	409.58	1.47E-06	4	3.
9.000	395.0	1.07E-03	746.74	456.17	1.33E-06	4	3.
10.000	395.0	9.75E-04	820.13	502.32	1.22E-06	4	3.
11.000	395.0	8.96E-04	892.62	548.08	1.12E-06	4	3.
12.000	395.0	8.30E-04	964.29	593.48	1.03E-06	4	3.
13.000	395.0	7.73E-04	1035.20	638.56	9.63E-07	4	4.
14.000	395.0	7.24E-04	1105.43	683.34	9.02E-07	3	0.
15.000	395.0	6.81E-04	1175.00	727.85	8.49E-07	3	0.
16.000	395.0	6.43E-04	1243.98	772.11	8.02E-07	3	0.
17.000	395.0	6.10E-04	1312.39	816.14	7.60E-07	3	0.
18.000	395.0	5.80E-04	1380.27	859.94	7.23E-07	3	0.
19.000	395.0	5.53E-04	1447.66	903.53	6.89E-07	3	0.
20.000	395.0	5.28E-04	1514.57	946.93	6.59E-07	3	0.
21.000	395.0	5.06E-04	1581.03	990.15	6.31E-07	3	0.
22.000	395.0	4.86E-04	1647.06	1033.19	6.06E-07	3	0.
23.000	395.0	4.67E-04	1712.68	1076.06	5.82E-07	3	0.
24.000	395.0	4.50E-04	1777.92	1118.77	5.61E-07	3	0.
25.000	395.0	4.34E-04	1842.78	1161.34	5.41E-07	3	0.
26.000	395.0	4.20E-04	1907.27	1203.75	5.23E-07	3	0.
27.000	395.0	4.06E-04	1971.43	1246.03	5.06E-07	3	0.
28.000	395.0	3.93E-04	2035.25	1288.18	4.90E-07	3	0.
29.000	395.0	3.81E-04	2098.75	1330.19	4.75E-07	3	0.
30.000	395.0	3.70E-04	2161.94	1372.09	4.61E-07	3	0.

1. PTDIS

RATIO IS THE HALF-WIDTH OF THE ISOPLETH COMPARED TO THE HALF-WIDTH OF A SECTOR OF 22.5 DEGREES AT THIS DISTANCE.

ISOPLETH VALUES (GRAMS PER CUBIC METER)

	9.99999E-07		5.00000E-06		1.00000E-05		2.50000E-05		5.00000E-05		7.50000E-05		1.00000E-04		5.00000E-04	
DIST. KM.	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO
1.000	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
2.000	550.	1.382	426.	1.071	360.	0.905	247.	0.620	94.	0.236	0.	0.0	0.	0.0	0.	0.0
3.000	1002.	1.679	867.	1.454	803.	1.346	708.	1.187	627.	1.052	575.	0.964	534.	0.896	186.	0.313
4.000	1361.	1.711	1197.	1.505	1119.	1.406	1006.	1.265	911.	1.146	851.	1.070	806.	1.013	478.	0.601
5.000	1682.	1.672	1484.	1.492	1390.	1.398	1254.	1.262	1142.	1.148	1070.	1.076	1016.	1.022	636.	0.640
6.000	1979.	1.659	1745.	1.463	1635.	1.370	1475.	1.237	1342.	1.125	1258.	1.054	1194.	1.001	745.	0.625
7.000	2260.	1.624	1990.	1.430	1862.	1.338	1677.	1.205	1523.	1.094	1425.	1.024	1351.	0.971	824.	0.592
8.000	2529.	1.590	2223.	1.397	2077.	1.306	1867.	1.174	1690.	1.063	1578.	0.992	1493.	0.939	880.	0.554
9.000	2789.	1.559	2446.	1.367	2283.	1.276	2047.	1.144	1848.	1.033	1722.	0.962	1626.	0.909	921.	0.515
10.000	3043.	1.530	2664.	1.340	2483.	1.249	2221.	1.117	2000.	1.006	1858.	0.935	1751.	0.681	948.	0.477
11.000	3292.	1.505	2876.	1.315	2677.	1.224	2389.	1.092	2145.	0.981	1989.	0.909	1870.	0.855	965.	0.442
12.000	3536.	1.482	3084.	1.292	2867.	1.202	2553.	1.070	2286.	0.958	2115.	0.887	1984.	0.832	971.	0.407
13.000	3776.	1.461	3288.	1.272	3053.	1.181	2712.	1.049	2423.	0.938	2237.	0.865	2094.	0.810	967.	0.374
14.000	4012.	1.441	3488.	1.253	3236.	1.162	2869.	1.031	2556.	0.918	2354.	0.846	2200.	0.791	952.	0.342
15.000	4245.	1.423	3684.	1.235	3415.	1.145	3021.	1.013	2686.	0.901	2469.	0.828	2302.	0.772	925.	0.310
16.000	4474.	1.406	3878.	1.219	3590.	1.129	3171.	0.997	2812.	0.884	2580.	0.811	2401.	0.755	884.	0.278
17.000	4701.	1.391	4068.	1.204	3764.	1.113	3318.	0.982	2936.	0.869	2687.	0.795	2496.	0.739	828.	0.245
18.000	4924.	1.376	4256.	1.189	3934.	1.099	3462.	0.967	3056.	0.854	2792.	0.780	2588.	0.723	752.	0.211
19.000	5145.	1.362	4442.	1.176	4102.	1.086	3603.	0.954	3174.	0.840	2894.	0.766	2678.	0.709	650.	0.172
20.000	5364.	1.349	4625.	1.163	4267.	1.073	3742.	0.941	3290.	0.827	2993.	0.753	2764.	0.695	504.	0.127
21.000	5580.	1.336	4805.	1.151	4430.	1.061	3878.	0.929	3402.	0.815	3090.	0.740	2848.	0.682	250.	0.060
22.000	5794.	1.325	4984.	1.139	4591.	1.050	4013.	0.918	3513.	0.803	3185.	0.728	2929.	0.670	0.	0.0
23.000	6006.	1.313	5160.	1.128	4750.	1.039	4145.	0.907	3622.	0.792	3277.	0.717	3008.	0.658	0.	0.0
24.000	6215.	1.302	5334.	1.118	4906.	1.028	4275.	0.896	3728.	0.781	3367.	0.706	3085.	0.647	0.	0.0
25.000	6423.	1.292	5507.	1.108	5061.	1.018	4404.	0.886	3832.	0.771	3454.	0.695	3159.	0.636	0.	0.0
26.000	6629.	1.282	5678.	1.098	5215.	1.009	4530.	0.877	3935.	0.761	3540.	0.685	3231.	0.625	0.	0.0
27.000	6833.	1.273	5847.	1.089	5366.	1.000	4655.	0.867	4035.	0.752	3624.	0.675	3301.	0.615	0.	0.0
28.000	7036.	1.264	6014.	1.080	5516.	0.991	4778.	0.858	4134.	0.743	3706.	0.666	3369.	0.605	0.	0.0
29.000	7237.	1.255	6180.	1.072	5664.	0.982	4900.	0.850	4231.	0.734	3786.	0.657	3434.	0.596	0.	0.0
30.000	7436.	1.247	6344.	1.064	5811.	0.974	5020.	0.842	4327.	0.726	3864.	0.648	3498.	0.587	0.	0.0

1. PTDIS

WIND SPEED = 5.0 M/SEC, STABILITY CLASS = 3,HEIGHT OF MIXING = 1500. METERS, AMBIENT TEMPERATURE = 319.7 DEG K.

EMISSION RATE (G/SEC)	PHYSICAL HEIGHT (M)	STACK GAS TEMP (DEG-K)	STACK GAS VELOCITY (M/SEC)	STACK DIAMETER (M)	STACK GAS VOL FLOW (M**3/SEC)	BRIGGS -F-	HEIGHT OF FINAL RISE (M)	DIST OF FINAL RISE (KM)
1605.00	213.5	431.0	27.45	8.24	1463.81	1179.92	753.0	2.015

DISTANCE KM	EFFECTIVE HEIGHT(M)	CONCENTRATION G/M**3	SIGY M.	SIGZ M.	CHI * U / Q SEC/M**3	MDUM	ANDUM
1.000	551.6	3.41E-20	103.11	61.14	1.06E-22	4	1.
2.000	750.3	2.88E-12	193.45	115.26	8.98E-15	4	1.
3.000	753.0	8.45E-08	279.00	167.01	2.63E-10	4	1.
4.000	753.0	3.21E-06	361.47	217.27	1.00E-08	4	1.
5.000	753.0	1.60E-05	441.64	266.47	4.99E-08	4	1.
6.000	753.0	3.57E-05	519.98	314.82	1.11E-07	4	1.
7.000	753.0	5.46E-05	596.81	362.49	1.70E-07	4	1.
8.000	753.0	6.85E-05	672.34	409.58	2.13E-07	4	1.
9.000	753.0	7.68E-05	746.74	456.17	2.39E-07	4	1.
10.000	753.0	8.07E-05	820.13	502.32	2.51E-07	4	1.
11.000	753.0	8.13E-05	892.62	548.08	2.53E-07	4	1.
12.000	753.0	8.00E-05	964.29	593.48	2.49E-07	4	1.
13.000	753.0	7.74E-05	1035.20	638.56	2.41E-07	4	1.
14.000	753.0	7.43E-05	1105.43	683.34	2.32E-07	4	1.
15.000	753.0	7.10E-05	1175.00	727.85	2.21E-07	4	2.
16.000	753.0	6.77E-05	1243.98	772.11	2.11E-07	4	2.
17.000	753.0	6.45E-05	1312.39	816.14	2.01E-07	4	2.
18.000	753.0	6.15E-05	1380.27	859.94	1.92E-07	4	2.
19.000	753.0	5.88E-05	1447.66	903.53	1.83E-07	4	2.
20.000	753.0	5.62E-05	1514.57	946.93	1.75E-07	4	2.
21.000	753.0	5.39E-05	1581.03	990.15	1.68E-07	4	2.
22.000	753.0	5.18E-05	1647.06	1033.19	1.61E-07	4	2.
23.000	753.0	4.98E-05	1712.68	1076.06	1.55E-07	4	2.
24.000	753.0	4.80E-05	1777.92	1118.77	1.49E-07	4	2.
25.000	753.0	4.63E-05	1842.78	1161.34	1.44E-07	4	2.
26.000	753.0	4.47E-05	1907.27	1203.75	1.39E-07	4	2.
27.000	753.0	4.33E-05	1971.43	1246.03	1.35E-07	4	2.
28.000	753.0	4.19E-05	2035.25	1288.18	1.31E-07	4	2.
29.000	753.0	4.07E-05	2098.75	1330.19	1.27E-07	4	2.
30.000	753.0	3.95E-05	2161.94	1372.09	1.23E-07	4	2.

1. PTDIS

RATIO IS THE HALF-WIDTH OF THE ISOPLETH COMPARED TO THE HALF-WIDTH OF A SECTOR OF 22.5 DEGREES AT THIS DISTANCE.

ISOPLETH VALUES (GRAMS PER CUBIC METER)

	9.99999E-07		5.00000E-06		1.00000E-05		2.50000E-05		5.00000E-05		7.50000E-05		1.00000E-04		5.00000E-04	
DIST. KM.	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO	HALF-WIDTH METERS	RATIO
1.000	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
2.000	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
3.000	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
4.000	553.	0.695	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
5.000	1041.	1.047	675.	0.679	429.	0.432	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
6.000	1391.	1.166	1032.	0.865	830.	0.696	440.	0.369	0.	0.0	0.	0.0	0.	0.0	0.	0.0
7.000	1689.	1.213	1306.	0.938	1100.	0.791	747.	0.537	251.	0.181	0.	0.0	0.	0.0	0.	0.0
8.000	1955.	1.229	1539.	0.967	1319.	0.830	955.	0.601	534.	0.336	0.	0.0	0.	0.0	0.	0.0
9.000	2201.	1.230	1746.	0.976	1508.	0.843	1119.	0.626	693.	0.387	164.	0.092	0.	0.0	0.	0.0
10.000	2431.	1.222	1935.	0.973	1676.	0.843	1256.	0.632	803.	0.404	313.	0.158	0.	0.0	0.	0.0
11.000	2648.	1.211	2109.	0.964	1828.	0.836	1372.	0.627	881.	0.403	360.	0.165	0.	0.0	0.	0.0
12.000	2855.	1.197	2271.	0.952	1967.	0.825	1471.	0.617	935.	0.392	346.	0.146	0.	0.0	0.	0.0
13.000	3054.	1.181	2424.	0.938	2095.	0.811	1557.	0.603	969.	0.375	263.	0.102	0.	0.0	0.	0.0
14.000	3245.	1.166	2569.	0.923	2215.	0.796	1632.	0.587	985.	0.354	0.	0.0	0.	0.0	0.	0.0
15.000	3431.	1.150	2707.	0.908	2327.	0.780	1698.	0.570	984.	0.330	0.	0.0	0.	0.0	0.	0.0
16.000	3612.	1.135	2840.	0.893	2433.	0.765	1756.	0.552	968.	0.305	0.	0.0	0.	0.0	0.	0.0
17.000	3789.	1.121	2968.	0.878	2534.	0.750	1807.	0.535	937.	0.278	0.	0.0	0.	0.0	0.	0.0
18.000	3962.	1.107	3093.	0.864	2631.	0.735	1853.	0.518	889.	0.249	0.	0.0	0.	0.0	0.	0.0
19.000	4133.	1.094	3214.	0.851	2725.	0.722	1893.	0.501	823.	0.218	0.	0.0	0.	0.0	0.	0.0
20.000	4300.	1.081	3333.	0.838	2815.	0.708	1929.	0.485	734.	0.185	0.	0.0	0.	0.0	0.	0.0
21.000	4465.	1.069	3448.	0.826	2903.	0.695	1960.	0.470	613.	0.147	0.	0.0	0.	0.0	0.	0.0
22.000	4628.	1.058	3562.	0.814	2987.	0.683	1988.	0.455	434.	0.100	0.	0.0	0.	0.0	0.	0.0
23.000	4789.	1.047	3673.	0.803	3069.	0.671	2011.	0.440	0.	0.0	0.	0.0	0.	0.0	0.	0.0
24.000	4947.	1.037	3782.	0.793	3149.	0.660	2031.	0.426	0.	0.0	0.	0.0	0.	0.0	0.	0.0
25.000	5104.	1.027	3888.	0.782	3227.	0.649	2046.	0.412	0.	0.0	0.	0.0	0.	0.0	0.	0.0
26.000	5259.	1.017	3993.	0.773	3302.	0.639	2058.	0.398	0.	0.0	0.	0.0	0.	0.0	0.	0.0
27.000	5412.	1.008	4097.	0.763	3375.	0.629	2066.	0.385	0.	0.0	0.	0.0	0.	0.0	0.	0.0
28.000	5564.	0.999	4198.	0.754	3447.	0.619	2070.	0.372	0.	0.0	0.	0.0	0.	0.0	0.	0.0
29.000	5714.	0.991	4298.	0.746	3516.	0.610	2071.	0.359	0.	0.0	0.	0.0	0.	0.0	0.	0.0
30.000	5862.	0.983	4396.	0.737	3583.	0.601	2067.	0.347	0.	0.0	0.	0.0	0.	0.0	0.	0.0

2. PTMAX

```
STABILITY = 1

 DART2 VERSION 74333
       700 FT STACK FOR 600 MW UNIT, SO2, SCRUBBER(N)=0.70

 ANALYSIS OF CONCENTRATION AS A FUNCTION OF STABILITY AND WIND SPEED. 1971 VERSION, D. B. TURNER.

 EMISSION RATE (G/SEC) =  481.50, PHY HT (M) =  213.50, STACK TEMP (DEG.K) = 431.00, STACK VEL (M/SEC) =  27.45,
 DIAM (M) =  8.24, VOLUME FLOW (CU M/SEC) = 1463.82

  WIND SPEED (M/SEC)   0.5          0.8          1.0          1.5          2.0          2.5          3.0          4.0          5.0

STABILITY = 1
 MAX CONC (G/CU M)   9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01 7.5592E-05 7.9466E-05 8.2255E-05
 DIST OF MAX (KM)    999.000(1) 999.000(1) 999.000(1) 999.000(1)    1.743      1.590      1.480
 PLUME HEIGHT (M)     6351.0(2)  4049.4(2)  3282.2(2)  2259.3(2)  1747.9(2)  1441.0(2)  1236.4(2)

STABILITY = 2
 MAX CONC (G/CU M)   9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01 2.1152E-05 2.3919E-05 2.6236E-05 2.9836E-05 3.2414E-05
 DIST OF MAX (KM)    999.000(1) 999.000(1) 999.000(1) 999.000(1)    9.597      8.050      6.997      5.659      4.845
 PLUME HEIGHT (M)     6351.0(2)  4049.4(2)  3282.2(2)  2259.3(2)  1747.9(2)  1441.0(2)  1236.4(2)   980.7(2)   827.2(2)

STABILITY = 3
 MAX CONC (G/CU M)                                               1.1667E-05 1.3618E-05 1.5332E-05 1.8134E-05 2.0271E-05
 DIST OF MAX (KM)                                                  27.078     21.906     18.520     14.365     11.914
 PLUME HEIGHT (M)                                                1747.9(2)  1441.0(2)  1236.4(2)   980.7(2)   827.2(2)

STABILITY = 4
 MAX CONC (G/CU M)   9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01 2.7356E-06 3.4006E-06
 DIST OF MAX (KM)    999.000(1) 999.000(1) 999.000(3) 999.000(3) 999.000(3) 999.000(3) 999.000(3) 165.745(3) 118.412(3)
 PLUME HEIGHT (M)     6351.0(2)  4049.4(2)  3282.2(2)  2259.3(2)  1747.9(2)  1441.0(2)  1236.4(2)   980.7(2)   827.2(2)

STABILITY = 5
 MAX CONC (G/CU M)                                               9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01 5.7715E-06
 DIST OF MAX (KM)                                                999.000(1) 999.000(1) 999.000(1) 999.000(1) 129.702(3)
 PLUME HEIGHT (M)                                                  460.7(2)   443.0(2)   429.5(2)   409.7(2)   395.6(2)

STABILITY = 6
 MAX CONC (G/CU M)                                               9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01 9.9000E 01
 DIST OF MAX (KM)                                                999.000(1) 999.000(1) 999.000(1) 999.000(1) 999.000(1)
 PLUME HEIGHT (M)                                                  418.6(2)   403.9(2)   392.7(2)   376.3(2)   364.6(2)
```

2. PTMAX

WIND SPEED (M/SEC)	7.0	10.0	12.0	15.0	20.0
STABILITY = 3					
MAX CONC (G/CU M)	2.3169E-05	2.5313E-05	2.5082E-05	2.6015E-05	
DIST OF MAX (KM)	9.178	7.170	6.404	5.642	
PLUME HEIGHT (M)	651.9(2)	520.4(2)	469.2(2)	418.1(2)	
STABILITY = 4					
MAX CONC (G/CU M)	4.9915E-06	5.8922E-06	6.4862E-06	7.0808E-06	7.4583E-06
DIST OF MAX (KM)	73.897	47.204	39.230	32.287	25.664
PLUME HEIGHT (M)	651.9(2)	520.4(2)	469.2(2)	418.1(2)	366.9(2)

(1) THE DISTANCE TO THE POINT OF MAXIMUM CONCENTRATION IS SO GREAT THAT THE SAME STABILITY IS NOT LIKELY TO PERSIST LONG ENOUGH FOR THE PLUME TO TRAVEL THIS FAR.

(2) THE PLUME IS OF SUFFICIENT HEIGHT THAT EXTREME CAUTION SHOULD BE USED IN INTERPRETING THIS COMPUTATION AS THIS STABILITY TYPE MAY NOT EXIST TO THIS HEIGHT. ALSO WIND SPEED VARIATIONS WITH HEIGHT MAY EXERT A DOMINATING INFLUENCE.

(3) NO COMPUTATION WAS ATTEMPTED FOR THIS HEIGHT AS THE POINT OF MAXIMUM CONCENTRATION IS GREATER THAN 100 KILOMETERS FROM THE SOURCE.

3. PTMTP

DBT51 VERSION 74333
DOWNWIND CONCENTRATION FOR 4 UNIT PLANT, SO2

* * * S O U R C E S * * *

NO	Q (G/SEC)	HP (M)	TS (DEG-K)	VS (M/SEC)	D(M)	VF(M**3/SEC)	R (KM)	S (KM)
1.	1605.00	213.5	431.0	27.4	8.24	0.0	0.0	0.0
2.	1605.00	213.5	431.0	27.4	8.24	0.0	0.100	0.0
3.	1605.00	213.5	431.0	27.4	8.24	0.0	0.200	0.0
4.	1605.00	213.5	431.0	27.4	8.24	0.0	0.300	0.0

* * * R E C E P T O R S * * *

NO.	RREC(KM)	SREC(KM)	Z (M)
1.	0.150	1.000	0.0
2.	0.150	2.000	0.0
3.	0.150	3.000	0.0
4.	0.150	4.000	0.0
5.	0.150	5.000	0.0
6.	0.150	6.000	0.0
7.	0.150	7.000	0.0
8.	0.150	8.000	0.0
9.	0.150	9.000	0.0
10.	0.150	10.000	0.0
11.	0.150	11.000	0.0
12.	0.150	12.000	0.0
13.	0.150	13.000	0.0
14.	0.150	14.000	0.0
15.	0.150	15.000	0.0
16.	0.150	16.000	0.0
17.	0.150	17.000	0.0
18.	0.150	18.000	0.0
19.	0.150	19.000	0.0
20.	0.150	20.000	0.0
21.	0.150	25.000	0.0
22.	0.150	30.000	0.0

* * * M E T E O R O L O G Y * * *

NO.	THETA(DEG)	U (M/SEC)	KST	HL (M)	T (DEG-K)	P (MB)
1.	180.	2.0	3	2500.	319.7	960.0

3. PTMTP

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***RECEPTOR NUMBER***
                        1.          2.          3.          4.          5.          6.          7.          8.          9.          10.         11.

SOURCE    FINAL HGT  PARTIAL CONCENTRATIONS (G/M**3)

   1.       1562.1  0.0         0.0         4.758E-22   1.779E-14   7.061E-11   6.744E-09   1.061E-07   6.280E-07   2.089E-06   4.844E-06   8.865E-06
   2.       1562.1  0.0         0.0         5.407E-22   1.920E-14   7.430E-11   6.997E-09   1.091E-07   6.419E-07   2.126E-06   4.916E-06   8.976E-06
   3.       1562.1  0.0         0.0         5.403E-22   1.919E-14   7.427E-11   6.995E-09   1.091E-07   6.416E-07   2.126E-06   4.915E-06   8.975E-06
   4.       1562.1  0.0         0.0         4.748E-22   1.776E-14   7.054E-11   6.739E-09   1.061E-07   6.276E-07   2.088E-06   4.842E-06   8.861E-06

                    TOTAL CONCENTRATION (G/M**3)

                    0.0         0.0         2.032E-21   7.394E-14   2.897E-10   2.747E-08   4.305E-07   2.539E-06   8.428E-06   1.952E-05   3.568E-05

***RECEPTOR NUMBER***
                        12.         13.         14.         15.         16.         17.         18.         19.         20.         21.         22.

SOURCE    FINAL HGT  PARTIAL CONCENTRATIONS (G/M**3)

   1.       1562.1  1.381E-05   1.919E-05   2.457E-05   2.962E-05   3.412E-05   3.798E-05   4.117E-05   4.372E-05   4.571E-05   4.964E-05   4.866E-05
   2.       1562.1  1.395E-05   1.937E-05   2.477E-05   2.983E-05   3.434E-05   3.819E-05   4.138E-05   4.393E-05   4.590E-05   4.978E-05   4.876E-05
   3.       1562.1  1.395E-05   1.936E-05   2.477E-05   2.983E-05   3.433E-05   3.819E-05   4.138E-05   4.392E-05   4.590E-05   4.977E-05   4.876E-05
   4.       1562.1  1.380E-05   1.918E-05   2.456E-05   2.961E-05   3.411E-05   3.796E-05   4.115E-05   4.371E-05   4.569E-05   4.962E-05   4.865E-05

                    TOTAL CONCENTRATION (G/M**3)

                    5.551E-05   7.710E-05   9.867E-05   1.189E-04   1.369E-04   1.523E-04   1.651E-04   1.753E-04   1.832E-04   1.988E-04   1.948E-04

***METEOROLOGY***
     NO.  THETA(DEG)    U (M/SEC)   KST      HL (M)   T (DEG-K)   P (MB)

      2.      180.         3.0        3       2500.      319.7      960.0

***RECEPTOR NUMBER***
                        1.          2.          3.          4.          5.          6.          7.          8.          9.          10.         11.

SOURCE    FINAL HGT  PARTIAL CONCENTRATIONS (G/M**3)                                                                                    10

   1.       1112.6  0.0         4.800E-23   7.293E-13   4.027E-09   2.239E-07   1.937E-06   6.869E-06   1.508E-05   2.503E-05   3.499E-05   4.373E-05
   2.       1112.6  0.0         6.266E-23   8.208E-13   4.346E-09   2.356E-07   2.010E-06   7.062E-06   1.541E-05   2.548E-05   3.550E-05   4.428E-05
   3.       1112.6  0.0         6.261E-23   8.203E-13   4.344E-09   2.355E-07   2.009E-06   7.061E-06   1.541E-05   2.548E-05   3.550E-05   4.427E-05
   4.       1112.6  0.0         4.789E-23   7.280E-13   4.022E-09   2.237E-07   1.936E-06   6.864E-06   1.507E-05   2.502E-05   3.497E-05   4.371E-05
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3. PTMTP

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                    TOTAL CONCENTRATION (G/M**3)

                0.0       2.212E-22 3.114E-12 1.674E-08 9.186E-07 7.893E-06 2.786E-05 6.096E-05 1.010E-04 1.410E-04 1.760E-04

* * * R E C E P T O R   N U M B E R * * *

                             12.       13.       14.       15.       16.       17.       18.       19.       20.       21.       22.

SOURCE     FINAL HGT  PARTIAL CONCENTRATIONS (G/M**3)

    1.        1112.6 5.073E-05 5.580E-05 5.936E-05 6.141E-05 6.234E-05 6.238E-05 6.178E-05 6.070E-05 5.928E-05 5.042E-05 4.227E-05
    2.        1112.6 5.127E-05 5.640E-05 5.984E-05 6.185E-05 6.273E-05 6.274E-05 6.209E-05 6.098E-05 5.954E-05 5.057E-05 4.235E-05
    3.        1112.6 5.126E-05 5.639E-05 5.983E-05 6.185E-05 6.273E-05 6.273E-05 6.209E-05 6.097E-05 5.953E-05 5.056E-05 4.235E-05
    4.        1112.6 5.071E-05 5.586E-05 5.934E-05 6.139E-05 6.232E-05 6.236E-05 6.176E-05 6.068E-05 5.927E-05 5.041E-05 4.226E-05

                    TOTAL CONCENTRATION (G/M**3)

                2.040E-04 2.245E-04 2.384E-04 2.465E-04 2.501E-04 2.502E-04 2.477E-04 2.433E-04 2.376E-04 2.020E-04 1.692E-04

* * * M E T E O R O L O G Y * * *
     NO.  THETA(DEG)    U (M/SEC)  KST     HL (M)   T (DEG-K)   P (MB)

       3.       180.         5.0          3      2500.      319.7      960.0

* * * P E C E P T O R   N U M B E R * * *

                              1.        2.        3.        4.        5.        6.        7.        8.        9.       10.       11.

SOURCE     FINAL HGT  PARTIAL CONCENTRATIONS (G/M**3)

    1.         753.0 1.137E-20 2.137E-12 7.321E-08 2.946E-06 1.513E-05 3.430E-05 5.293E-05 6.682E-05 7.530E-05 7.933E-05 8.016E-05
    2.         753.0 3.035E-20 2.789E-12 8.320E-08 3.179E-06 1.593E-05 3.558E-05 5.443E-05 6.830E-05 7.665E-05 8.050E-05 8.116E-05
    3.         753.0 3.030E-20 2.787E-12 8.316E-08 3.178E-06 1.592E-05 3.557E-05 5.442E-05 6.829E-05 7.664E-05 8.049E-05 8.115E-05
    4.         753.0 1.101E-20 2.132E-12 7.310E-08 2.943E-06 1.512E-05 3.427E-05 5.290E-05 6.678E-05 7.526E-05 7.929E-05 8.013E-05
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3. PTMTP

TOTAL CONCENTRATION (G/M**3)

8.433E-20 9.846E-12 3.127E-07 1.225E-05 6.210E-05 1.397E-04 2.147E-04 2.702E-04 3.038E-04 3.196E-04 3.226E-04

*** RECEPTOR NUMBER ***

	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
SOURCE	FINAL HGT	PARTIAL CONCENTRATIONS (G/M**3)									
1.	753.0	7.890E-05	7.634E-05	7.305E-05	6.941E-05	6.566E-05	6.193E-05	5.834E-05	5.491E-05	5.169E-05	3.863E-05	2.985E-05
2.	753.0	7.974E-05	7.704E-05	7.364E-05	6.991E-05	6.607E-05	6.229E-05	5.864E-05	5.517E-05	5.191E-05	3.874E-05	2.991E-05
3.	752.0	7.973E-05	7.703E-05	7.363E-05	6.990E-05	6.607E-05	6.228E-05	5.863E-05	5.517E-05	5.191E-05	3.874E-05	2.991E-05
4.	753.0	7.886E-05	7.631E-05	7.302E-05	6.939E-05	6.563E-05	6.191E-05	5.832E-05	5.490E-05	5.168E-05	3.862E-05	2.985E-05

TOTAL CONCENTRATION (G/M**3)

3.172E-04 3.067E-04 2.933E-04 2.786E-04 2.634E-04 2.484E-04 2.339E-04 2.201E-04 2.072E-04 1.547E-04 1.195E-04

*** METEOROLOGY ***

NO.	THETA(DEG)	U (M/SEC)	KST	HL (M)	T (DEG-K)	P (MB)
4.	180.	7.0	3	2500.	319.7	960.0

*** RECEPTOR NUMBER ***

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
SOURCE	FINAL HGT	PARTIAL CONCENTRATIONS (G/M**3)									
1.	598.8	3.781E-15	3.637E-09	2.191E-06	1.912E-05	4.688E-05	7.009E-05	8.355E-05	8.881E-05	8.873E-05	8.563E-05	8.100E-05
2.	598.8	9.671E-15	4.749E-09	2.490E-06	2.063E-05	4.933E-05	7.271E-05	8.591E-05	9.078E-05	9.032E-05	8.689E-05	8.201E-05
3.	598.8	9.658E-15	4.746E-09	2.489E-06	2.063E-05	4.932E-05	7.269E-05	8.589E-05	9.076E-05	9.031E-05	8.688E-05	8.199E-05
4.	598.8	3.766E-15	3.630E-09	2.188E-06	1.910E-05	4.684E-05	7.003E-05	8.349E-05	8.876E-05	8.869E-05	8.558E-05	8.096E-05

3. PTMTP

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* * * R E C E P T O R   N U M B E R * * *
                        12.         13.         14.         15.         16.         17.         18.         19.         20.         21.         22.

SOURCE      FINAL HGT   PARTIAL CONCENTRATIONS (G/M**3)

    1.          598.8 7.575E-05 7.040E-05 6.522E-05 6.035E-05 5.585E-05 5.173E-05 4.797E-05 4.456E-05 4.147E-05 2.979E-05 2.247E-05
    2.          598.8 7.656E-05 7.105E-05 6.575E-05 6.078E-05 5.621E-05 5.202E-05 4.822E-05 4.477E-05 4.165E-05 2.987E-05 2.251E-05
    3.          598.8 7.655E-05 7.104E-05 6.574E-05 6.078E-05 5.620E-05 5.202E-05 4.822E-05 4.477E-05 4.164E-05 2.987E-05 2.251E-05
    4.          598.8 7.572E-05 7.037E-05 6.520E-05 6.033E-05 5.583E-05 5.171E-05 4.796E-05 4.455E-05 4.146E-05 2.978E-05 2.246E-05

                      TOTAL CONCENTRATION (G/M**3)

                      3.046E-04 2.829E-04 2.619E-04 2.422E-04 2.241E-04 2.075E-04 1.924E-04 1.787E-04 1.662E-04 1.193E-04 8.995E-05

* * * M E T E O R O L O G Y * * *
    NO.  THETA(DEG)   U (M/SEC)  KST     HL (M)  T (DEG-K)   P (MB)

     5.         180.       10.0         3     2500.      319.7      960.0

* * * R E C E P T O R   N U M B E R * * *
                        1.          2.          3.          4.          5.          6.          7.          8.          9.          10.         11.

SOURCE      FINAL HGT   PARTIAL CONCENTRATIONS (G/M**3)

    1.          483.2 8.875E-12 2.718E-07 1.444E-05 5.035E-05 7.918E-05 9.221E-05 9.413E-05 9.025E-05 8.389E-05 7.680E-05 6.982E-05
    2.          483.2 2.270E-11 3.548E-07 1.641E-05 5.423E-05 8.333E-05 9.566E-05 9.679E-05 9.225E-05 8.539E-05 7.794E-05 7.069E-05
    3.          483.2 2.267E-11 3.546E-07 1.640E-05 5.431E-05 8.330E-05 9.564E-05 9.677E-05 9.223E-05 8.538E-05 7.792E-05 7.068E-05
    4.          483.2 8.840E-12 2.712E-07 1.442E-05 5.030E-05 7.912E-05 9.214E-05 9.407E-05 9.020E-05 8.385E-05 7.676E-05 6.979E-05

                      TOTAL CONCENTRATION (G/M**3)

                      6.309E-11 1.252E-06 6.167E-05 2.093E-04 3.249E-04 3.756E-04 3.818E-04 3.649E-04 3.385E-04 3.094E-04 2.810E-04

* * * R E C E P T O R   N U M B E R * * *
                        12.         13.         14.         15.         16.         17.         18.         19.         20.         21.         22.

SOURCE      FINAL HGT   PARTIAL CONCENTRATIONS (G/M**3)

    1.          483.2 6.333E-05 5.745E-05 5.220E-05 4.754E-05 4.342E-05 3.977E-05 3.654E-05 3.368E-05 3.112E-05 2.184E-05 1.623E-05
    2.          483.2 6.400E-05 5.798E-05 5.262E-05 4.788E-05 4.370E-05 4.000E-05 3.673E-05 3.384E-05 3.126E-05 2.190E-05 1.627E-05
    3.          483.2 6.399E-05 5.797E-05 5.261E-05 4.788E-05 4.369E-05 4.000E-05 3.673E-05 3.383E-05 3.125E-05 2.190E-05 1.626E-05
    4.          483.2 6.330E-05 5.742E-05 5.218E-05 4.752E-05 4.341E-05 3.976E-05 3.653E-05 3.367E-05 3.112E-05 2.183E-05 1.623E-05
```

3. PTMTP

TOTAL CONCENTRATION (G/M**3)

2.540E-04 2.308E-04 2.096E-04 1.908E-04 1.742E-04 1.595E-04 1.465E-04 1.350E-04 1.248E-04 8.746E-05 6.499E-05

*** METEOROLOGY ***

NO.	THETA(DEG)	U (M/SEC)	KST	HL (M)	T (DEG-K)	P (MB)
6.	180.	15.0	3	2500.	319.7	960.0

*** RECEPTOR NUMBER ***

		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
SOURCE	FINAL HGT	PARTIAL CONCENTRATIONS (G/M**3)										
1.	393.3	1.237E-09	3.440E-06	3.953E-05	7.734E-05	9.195E-05	9.148E-05	8.470E-05	7.610E-05	6.759E-05	5.985E-05	5.307E-05
2.	393.3	3.164E-09	4.492E-06	4.493E-05	8.346E-05	9.676E-05	9.491E-05	8.709E-05	7.779E-05	6.880E-05	6.074E-05	5.373E-05
3.	393.3	3.160E-09	4.489E-06	4.492E-05	8.343E-05	9.673E-05	9.488E-05	8.707E-05	7.777E-05	6.878E-05	6.073E-05	5.373E-05
4.	393.3	1.232E-09	3.434E-06	3.948E-05	7.726E-05	9.187E-05	9.142E-05	8.464E-05	7.605E-05	6.755E-05	5.982E-05	5.305E-05

TOTAL CONCENTRATION (G/M**3)

8.794E-09 1.585E-05 1.689E-04 3.215E-04 3.773E-04 3.727E-04 3.435E-04 3.077E-04 2.727E-04 2.411E-04 2.136E-04

*** RECEPTOR NUMBER ***

		12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
SOURCE	FINAL HGT	PARTIAL CONCENTRATIONS (G/M**3)										
1.	393.3	4.722E-05	4.218E-05	3.786E-05	3.414E-05	3.092E-05	2.813E-05	2.570E-05	2.356E-05	2.168E-05	1.499E-05	1.104E-05
2.	393.3	4.772E-05	4.257E-05	3.817E-05	3.439E-05	3.112E-05	2.829E-05	2.583E-05	2.367E-05	2.177E-05	1.503E-05	1.106E-05
3.	393.3	4.771E-05	4.257E-05	3.816E-05	3.438E-05	3.112E-05	2.829E-05	2.583E-05	2.367E-05	2.177E-05	1.503E-05	1.106E-05
4.	393.3	4.720E-05	4.217E-05	3.785E-05	3.413E-05	3.091E-05	2.812E-05	2.569E-05	2.355E-05	2.168E-05	1.498E-05	1.104E-05

TOTAL CONCENTRATION (G/M**3)

1.898E-04 1.695E-04 1.520E-04 1.370E-04 1.241E-04 1.128E-04 1.030E-04 9.446E-05 8.690E-05 6.003E-05 4.420E-05

APPENDIX B (Continued)

3. PTMTP

AVERAGE CONCENTRATIONS FOR 6 HOURS.

RECEPTOR NUMBER

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
SOURCE	PARTIAL CONCENTRATIONS (G/M**3)										
1.	2.076E-10	6.193E-07	9.373E-06	2.496E-05	3.890E-05	4.834E-05	5.371E-05	5.628E-05	5.711E-05	5.691E-05	5.611E-05
2.	5.312E-10	8.085E-07	1.065E-05	2.694E-05	4.093E-05	5.015E-05	5.523E-05	5.753E-05	5.813E-05	5.775E-05	5.681E-05
3.	5.305E-10	8.080E-07	1.065E-05	2.693E-05	4.092E-05	5.013E-05	5.522E-05	5.752E-05	5.812E-05	5.774E-05	5.680E-05
4.	2.069E-10	6.182E-07	9.360E-06	2.493E-05	3.886E-05	4.830E-05	5.368E-05	5.625E-05	5.708E-05	5.688E-05	5.608E-05
	TOTAL CONCENTRATION (G/M**3)										
	1.476E-09	2.854E-06	4.003E-05	1.038E-04	1.596E-04	1.969E-04	2.178E-04	2.276E-04	2.304E-04	2.293E-04	2.258E-04

RECEPTOR NUMBER

	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
SOURCE	PARTIAL CONCENTRATIONS (G/M**3)										
1.	5.495E-05	5.357E-05	5.204E-05	5.041E-05	4.872E-05	4.699E-05	4.525E-05	4.352E-05	4.183E-05	3.422E-05	2.842E-05
2.	5.554E-05	5.407E-05	5.246E-05	5.077E-05	4.903E-05	4.726E-05	4.548E-05	4.373E-05	4.200E-05	3.431E-05	2.848E-05
3.	5.553E-05	5.406E-05	5.246E-05	5.077E-05	4.902E-05	4.725E-05	4.548E-05	4.372E-05	4.200E-05	3.431E-05	2.848E-05
4.	5.493E-05	5.355E-05	5.202E-05	5.040E-05	4.870E-05	4.697E-05	4.524E-05	4.351E-05	4.181E-05	3.421E-05	2.841E-05
	TOTAL CONCENTRATION (G/M**3)										
	2.210E-04	2.153E-04	2.090E-04	2.023E-04	1.955E-04	1.885E-04	1.814E-04	1.743E-04	1.676E-04	1.371E-04	1.138E-04